INSTITUTION

OF

MECHANICAL ENGINEERS.

28063

PROCEEDINGS.

1884.

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CONTENTS.

1884.

ERRATUM IN PROCEEDINGS 1883.

Page 575, lines 11–8 from bottom, instead of "In most of the pits . . . . discharging level" the sentence should read as follows:—"In most of the pits the descending cage of empty trams is received at the pit bottom upon a balanced platform: as soon as the lower floor of the cage has been loaded with a full tram, the platform is overbalanced and the cage is let down gently by a brake till its upper floor comes to the level for charging."

ERRATUM IN PROCEEDINGS 1884.

Page 62, line 2 from bottom, for "Mr. John Hayes" *read* "the late Mr. Edward Hayes."

1884.

PRESIDENT.

I. Lowthian Bell, F.R.S., ... Rounton Grange ...... Northallerton.

PAST-PRESIDENTS.

Sir William G. Armstrong, C.B., D.C.L., LL.D., F.R.S., Newcastle-on-Tyne.
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James Kennedy, ... Liverpool.
John Ramsbottom, ... Alderley Edge.
John Robinson, ... Manchester.
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Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., .. Manchester.
Sir William Fairbairn, Bart., LL.D., F.R.S., (*deceased* 1874).
Robert Napier, ... (*deceased* 1876).
John Penn, F.R.S., ... (*deceased* 1878).
Sir William Siemens, D.C.L., LL.D., F.R.S., . (*deceased* 1883).
George Stephenson, ... (*deceased* 1848).
Robert Stephenson, F.R.S., ... (*deceased* 1859).

VICE-PRESIDENTS.

Charles Cochrane, ... Stourbridge.
Thomas R. Crampton, ... London.
Jeremiah Head, ... Middlesbrough.
Richard Peacock, ... Manchester.
George B. Rennie, ... London.
Francis W. Webb, ... Crewe.

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Daniel Adamson, ... Manchester.
William Anderson, ... London.
William Boyd, ... Newcastle-on-Tyne.
David Greig, ... Leeds.
Samuel W. Johnson, ... Derby.
J. Hawthorn Kitson, ... Leeds.
Francis C. Marshall, ... Newcastle-on-Tyne.
Arthur Paget, ... Loughborough.
R. Price-Williams, ... London.
Sir James Ramsden, ... Barrow-in-Furness.
E. Windsor Richards, ... Middlesbrough.
William Richardson, ... Oldham.
Sir Bernhard Samuelson, Bart., M.P., F.R.S., ... London.
Joseph Tomlinson, Jun., ... London.
Ralph H. Tweddell, ... London.

TREASURER.

Thomas Druitt.

SECRETARY.

Alfred Bache,

Institution of Mechanical Engineers, 10 *Victoria Chambers, London, S.W.*

Institution of Mechanical Engineers.

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

1884.

HONORARY LIFE MEMBERS.

1883. Abel, Sir Frederick Augustus, C.B., F.R.S., Royal Arsenal, Woolwich.
1878. Crawford and Balcarres, Earl of, F.R.S., 47 Brook Street, Grosvenor Square, London, W.; Haigh Hall, Wigan; and Observatory, Dunecht, Aberdeen.
1883. Kennedy, Alexander Blackie William, Professor of Engineering, University College, Gower Street, London, W.C.
1878. Rayleigh, Lord, F.R.S., 4 Carlton Gardens, London, S.W.; and Terling Place, Witham, Essex.
1883. Trasenster, L., Rector of the University of Liége, 9 Quai de l'Industrie, Liége, Belgium.
1867. Tresca, Henri, Member of the Academy, &c., Conservatoire National des Arts et Métiers, Paris.

MEMBERS.

1878. Abbott, Thomas, Northgate Iron Works, Newark.
1883. Abbott, William Sutherland, Locomotive and Mechanical Engineer, Alagoas Railway, Maceio, Brazil.
1861. Abel, Charles Denton, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C.
1874. Abernethy, James, F.R.S.E., 4 Delahay Street, Westminster, S.W.
1876. Adams, Henry, 60 Queen Victoria Street, London, E.C.

1879. Adams, William, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.W.

1848. Adams, William Alexander, Gaines, Worcester.

1881. Adams, William John, Messrs. Everitt Adams and Co., 35 Queen Victoria Street, London, E.C.

1859. Adamson, Daniel, Engineering Works, Dukinfield, near Manchester; and The Towers, Didsbury, Manchester.

1871. Adamson, Joseph, Messrs. Joseph Adamson and Co., Hyde, near Manchester.

1878. Adcock, Francis Louis, Post Office, Cape Town, Cape of Good Hope: (or care of William R. Adcock, 17 Rue Neuve de Berry, Havre, France.)

1851. Addison, John, 6 Delahay Street, Westminster, S.W.

1858. Albaret, Auguste, Engine Works, Liancourt-Rantigny, Oise, France.

1870. Alexander, Alfred, King William's Town, Cape of Good Hope: (or care of William Alexander, East Cranhams, Cirencester.)

1883. Allam, Edwin Clerk, Normanhurst, Romford.

1847. Allan, Alexander, Glen House, The Valley, Scarborough.

1875. Allan, George, New British Iron Works, Corngreaves, near Birmingham; and Corngreaves Hall, near Birmingham.

1884. Allen, Alfred Evans, 37 Wellington Street, Hull.

1881. Allen, Percy Ruskin, Anglo-American Brush Electric Light Co., Victoria Works, Vine Street, York Road, Lambeth, London, S.E.; and Woodberrie Hill, Loughton, Essex.

1884. Allen, Samuel Wesley, 65 Bute Street, Bute Docks, Cardiff.

1865. Allen, William Daniel, Bessemer Steel Works, Sheffield.

1882. Allen, William Milward, Assistant Engineer, Engine Boiler and Employers' Liability Insurance Co., 12 King Street, Manchester.

1870. Alley, John, care of W. Cuningham, Moscow.

1877. Alley, Stephen, Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow.

1865. Alleyne, Sir John Gay Newton, Bart., Chevin, Belper.

1884. Alleyne, Reynold Henry Newton, Messrs. Scriven and Co., Old Foundry, Marsh Lane, Leeds.

1872. Alliott, James Bingham, Messrs. Manlove Alliott Fryer and Co., Bloomsgrove Works, Ilkeston Road, Nottingham.

1871. Allport, Howard Aston, Dodworth Grove, Barnsley.

1884. Almond, Harry John, Messrs. John Spencer and Sons, Newburn Steel Works, Newcastle-on-Tyne.

1867. Amos, James Chapman, West Barnet Lodge, Lyonsdown, Barnet.

1876. Anderson, Henry John Card, Temple Sheen, East Sheen, London, S.W.

1856. Anderson, Sir John, LL.D., F.R.S.E., Fairleigh, The Mount, St. Leonard's-on-Sea.

1881. Anderson, Joseph Liddell, Messrs. Anderson and Gallwey, Hydraulic Machine Works, Lot's Road, Chelsea, London, S.W.

1884. Anderson, Samuel, General Manager, Westbury Iron Works, Westbury, Wiltshire.

1856. Anderson, William, Messrs. Easton and Anderson, Erith Iron Works, Erith, London, S.E.; and 3 Whitehall Place, London, S.W.

1878. Angas, William Moore, Darlington Wagon and Engineering Works, Darlington.

1858. Appleby, Charles Edward, Charing Cross Chambers, Duke Street, Adelphi, London, W.C.

1867. Appleby, Charles James, Messrs. Appleby Brothers, 89 Cannon Street, London, E.C.; and East Greenwich Works, London, S.E.

1874. Aramburu y Silva, Fernando, Messrs. Aramburu and Sons, Cartridge Manufacturers, Calle de la Virgen de las Azucenas, Madrid: (or care of Manuel Cardenosa, 86 Great Tower Street, London, E.C.)

1881. Archbold, Joseph Gibson, Messrs. Fawcett Preston and Co., Phœnix Foundry, 17 York Street, Liverpool.

1874. Archer, David, Central Chambers, Corporation Street, Birmingham; and 275 Pershore Road, Birmingham.

1883. Arens, Henrique, Messrs. Arens and Irmaos, Engineering Works, Rio de Janeiro, Brazil: (or care of Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.)

1882. Armer, James, Messrs. J. and E. Hall, Iron Works, Dartford.

1859. Armitage, William James, Farnley Iron Works, Leeds.

1879. Armstrong, Alexander, Melrose, North Shore, Auckland, New Zealand.

1866. Armstrong, George, Great Western Railway, Locomotive Department, Stafford Road Works, Wolverhampton.

1882. Armstrong, George Frederick, Professor of Engineering, Yorkshire College of Science, Leeds.

1876. Armstrong, William, Jun., Mining Engineer, Wingate Colliery, County Durham.

1858. Armstrong, Sir William George, C.B., D.C.L., LL.D., F.R.S., Elswick Newcastle-on-Tyne; and Cragside, Morpeth.

1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1873. Arnold, David Nelson, Manager, Midland Railway-Carriage and Wagon Works, Lander Street, Birmingham; Abbey Works, Shrewsbury; and Clive House, Shrewsbury.

1879. Arrol, Thomas Arthur, Messrs. Arrol Brothers, Germiston Iron Works, Glasgow; and 18 Blythswood Square, Glasgow.

1873. Ashbury, Thomas, 28A Market Street, Manchester. (*Life Member.*)

1884. Ashwell, Frank, 10 Erskine Street, Leicester.

1881. Aspinall, John Audley Frederick, Locomotive Superintendent, Great Southern and Western Railway, Dublin.

1877. Astbury, James, Smethwick Foundry, near Birmingham.

1870. Atkinson, Charles Fanshawe, Messrs. Marriott and Atkinson, Fitzalan Steel Works, Sheffield.

1875. Atkinson, Edward, Messrs. Richards and Atkinson, Bank Street, Royal Exchange, Manchester; and 4 Richmond Hill, Bowdon, Cheshire. (*Life Member.*)

1882. Aveling, Thomas Lake, Messrs. Aveling and Porter, Rochester.

1879. Bagot, Alan Charles, care of Edward W. Bowles, 86 Cambridge Street, London, S.W.

1872. Bagshaw, Walter, Messrs. J. Bagshaw and Sons, Victoria Foundry, Batley.

1865. Bailey, John, Messrs. Courtney Stephens and Bailey, Blackhall Place Iron Works, Dublin.

1880. Baillie, Robert, Messrs. Westwood Baillie and Co., London Yard Iron Works, Poplar, London, E.

1872. Bailly, Philimond, 62 Rue de la Victoire, Paris.

1880. Bain, William Neish, Messrs. Kyle and Bain, Hong Kong Ice Works, Eastpoint, Hong Kong, China: (or care of George Ogilvie, 110 George Street, Glasgow.)

1873. Baird, George, St. Petersburg; and 13 Berkeley Square, London, W.

1875. Bakewell, Herbert James, Engineer, Department of the Controller of the Navy, Admiralty, Whitehall, London, S.W.

1879. Baldwin, Thomas, 27 Brunswick Street, Cheetham, Manchester.

1877. Bale, Manfred Powis, Appold Street, Finsbury, London, E.C.

1884. Balmokand, Lala, Assistant Engineer, Public Works Department, Punjaub, India; care of Lala Shamba Das, Said Mitha, Lahore, India.

1879. Banderali, David, Assistant Locomotive and Carriage Superintendent, Chemin de fer du Nord, Paris.

1882. Barber, John, 20 Park Row, Leeds.

1870. Barber, Thomas, Mining Engineer, High Park Collieries, Eastwood, Nottinghamshire.

1870. Barclay, Arthur, 12 York Street, Covent Garden, London, W.C.

1884. Barlow, Elias, Messrs. William Muir and Co., Britannia Works, Sherborne Street, Strangeways, Manchester.

1882. Barlow, Henry Bernoulli, Cornbrook Heald Works, Chester Road, Manchester.

1875. Barlow, William Henry, F.R.S., 2 Old Palace Yard, Westminster, S.W.
1880. Barlow-Massicks, Thomas, Millom Iron Works, Millom, Cumberland.
1881. Barnett, John Davis, Mechanical Superintendent, Midland Railway, Port Hope, Ontario, Canada.
1884. Barr, Archibald, Professor of Engineering, Yorkshire College, Leeds.
1878. Barr, James, Works Manager, Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow.
1883. Barras, Harry Haywood, Locomotive Superintendent, Great Western Railway of Brazil, Pernambuco, Brazil; (or care of George Thomas Barras, 7 Howard Street, Rotherham.)
1879. Barratt, Samuel, Engineer and Manager, Corporation Gas Works, Gaythorn Station, Hulme, Manchester.
1882. Barrett, John James, Sewlal Motilal Cotton Mill, Tardeo, Bombay.
1862. Barrow, Joseph, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow.
1867. Barrows, Thomas Welch, Messrs. Barrows and Stewart, Portable Engine Works, Banbury.
1871. Barry, John Wolfe, 23 Delahay Street, Westminster, S.W.
1883. Bartlett, James Herbert, 148 Mansfield Street, Montreal, Canada.
1883. Bastin, Edwin Philp, Alliance Engineering Works, West Drayton, near Uxbridge.
1860. Batho, William Fothergill, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1881. Bawden, William, Assistant Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.
1872. Bayliss, Thomas Richard, Adderley Park Rolling Mills and Metal Works, Birmingham; and Belmont, Northfield, Birmingham.
1877. Beale, William Phipson, 12 Old Square, London, W.C.; and 19 Upper Phillimore Gardens, Kensington, London, W.
1881. Beattie, Alfred Luther, Manager, New Zealand Railway Workshops, Dunedin, Otago, New Zealand.
1882. Beattie, Frank, Queen Chambers, 88 Colmore Row, Birmingham.
1880. Beaumont, William Worby, 163 Strand, London, W.C.
1859. Beck, Edward, Dallam Forge, Warrington; and 21 Bold Street, Warrington. (*Life Member.*)
1873. Beck, William Henry, 115 Cannon Street, London, E.C.
1875. Beckwith, John Henry, Engineer to Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester.
1882. Bedson, Joseph Phillips, Messrs. Richard Johnson and Nephew, Bradford Iron Works. Manchester.
1875. Beeley, Thomas, Engineer and Boiler Maker, Hyde Junction Iron Works, Hyde, near Manchester.

1884. Beetlestone, George John, Penarth Dock Extension Works, Penarth.

1858. Bell, Isaac Lowthian, F.R.S., Clarence Iron Works, Middlesbrough; Rounton Grange, Northallerton; Reform Club, Pall Mall, London, S.W.; and care of the Hon. E. Lyulph Stanley, 82 Harley Street, London, W.

1880. Bell, William Henry, Bolivia: care of Sir W. G. Armstrong Mitchell and Co., 8 Great George Street, Westminster, S.W.

1879. Bellamy, Charles James, 38 Parliament Street, Westminster, S.W.

1868. Belliss, George Edward, Steam Engine and Boiler Works, Ledsam Street, Birmingham.

1878. Belsham, Maurice, Messrs. Price and Belsham, 52 Queen Victoria Street, London, E.C.

1880. Benham, Percy, Messrs. Benham, 66 Wigmore Street, London, W.

1854. Bennett, Peter Duckworth, Horseley Iron Works, Tipton.

1872. Bennett, William, Jun., 38 Sir Thomas' Buildings, Liverpool.

1861. Bessemer, Sir Henry, F.R.S., Denmark Hill, London, S.E.

1866. Bevis, Restel Ratsey, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead; and Manor Hill, Birkenhead.

1874. Bewick, Thomas John, Mining Engineer, Haydon Bridge, Northumberland.

1870. Bewlay, Hubert, Birmingham Heath Boiler Works, Spring Hill, Birmingham.

1882. Bewley, Thomas Arthur, Messrs. Bewley Webb and Co., Port of Dublin Ship Yard, Dublin.

1883. Bicknell, Edward, Locomotive Superintendent, La Guaira and Caracas Railway, Venezuela; and 16 Miles Road, Clifton, Bristol.

1884. Bika, Léon Joseph, Locomotive Engineer-in-Chief, Belgian State Railway, 29 Rue des Palais, Bruxelles.

1877. Birch, Robert William Peregrine, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1847. Birley, Henry, Haigh Foundry, near Wigan.

1875. Bisset, William Harvey, Board of Trade Office, Falmouth; and Erin Lodge, Green Bank, Falmouth.

1879. Black, William, Messrs. Black Hawthorn and Co., Gateshead.

1862. Blake, Henry Wollaston, F.R.S., Messrs. James Watt and Co., 90 Leadenhall Street, London, E.C.

1881. Blechynden, Alfred, Rio Tinto Mines, Huelva, Spain.

1867. Bleckly, John James, Bewsey Iron Works, Warrington; and Daresbury Lodge, Altrincham.

1881. Bocquet, William, Locomotive Engineer, Scinde Punjaub and Delhi Railway, Lahore, India.

1883. Bodden, George, Messrs. William Bodden and Son, Hargreaves Spindle and Flyer Works, Oldham.

1863. Boeddinghaus, Julius, Electrotechniker, Düsseldorf, Germany.
1884. Bone, William Lockhart, Works of the Ant and Bee, West Gorton, Manchester.
1880. Borodin, Alexander, Engineer-in-Chief, Russian South Western Railways, Kieff, Russia.
1869. Borrie, John, Cranbourne Terrace, Yarm Lane, Stockton-on-Tees.
1878. Bourdon, François Edouard, 74 Faubourg du Temple, Paris: (or care of Messrs. Negretti and Zambra, Holborn Viaduct, London, E.C.)
1884. Bourne, James Johnstone, Abberley, Wallington, Surrey.
1879. Bourne, William Temple, Messrs. Bourne and Grove, Bridge Steam Saw Mills, Worcester.
1879. Bovey, Henry Taylor, Professor of Engineering, McGill University, Montreal, Canada.
1880. Bow, William, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley.
1870. Bower, Anthony, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.
1858. Bower, John Wilkes, Pleasington, near Blackburn. (*Life Member.*)
1882. Bowie, Augustus Jesse, Jun., Mining and Hydraulic Engineer, P.O. Drawer 2220, San Francisco, California, United States.
1869. Boyd, William, Wallsend Slipway and Engineering Works, Wallsend, near Newcastle-on-Tyne.
1884. Boyer, Robert Skeffington, Pier Head Chambers, Cardiff.
1882. Bradley, Frederic, Clensmore Foundry, Kidderminster.
1878. Bradley, Frederick Augustus, 39 Queen Victoria Street, London, E.C.
1881. Bradley, Thomas, Wellington Foundry, Newark.
1854. Bragge, William, Clarendon House, 59 Hall Road, Handsworth, Birmingham.
1878. Braithwaite, Charles C., 35 King William Street, London Bridge, London, E.C.
1875. Braithwaite, Richard Charles, Bescot Lodge, Walsall.
1854. Bramwell, Sir Frederick Joseph, F.R.S., 5 Great George Street, Westminster, S.W.
1868. Breeden, Joseph, New Mill Works, Fazeley Street, Birmingham.
1883. Bricknell, Augustus Lea, Merlin Engineering Works, Brixton Rise, London, S.W.
1881. Briggs, John Henry, Engineer, Kimberley Water Works, Kimberley, South Africa : (or care of Charles Briggs, Howden.)
1880. Bright, Thomas Smith, Picton Villa, Carmarthen.
1865. Brock, Walter, Messrs. Denny and Co., Engine Works, Dumbarton.
1879. Brodie, John Shanks, Town Surveyor and Harbour Engineer, Town Hall, Whitehaven.

1852. Brogden, Henry, Hale Lodge, Altrincham, near Manchester. (*Life Member.*)

1877. Bromley, Massey, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1880. Brophy, Michael Mary, Messrs. James Slater and Co., 251 High Holborn, London, W.C.

1874. Brotherhood, Peter, 15 and 17 Belvedere Road, Lambeth, London, S.E.; and 94 Cromwell Road, South Kensington, London, S.W.

1866. Brown, Andrew Betts, Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.

1879. Brown, Charles, Manager, Maschinenfabrik, Oerlikon, Switzerland: (or care of Dr. Gardiner Brown, 9 St. Thomas' Street, London Bridge, London, S.E.)

1880. Brown, Francis Robert Fountaine, Mechanical Superintendent, Canadian Pacific Railway, Montreal, Canada.

1881. Brown, George William, Reading Iron Works, Reading.

1863. Brown, Henry, Waterloo Chambers, Waterloo Street, Birmingham.

1884. Brown, Oswald, 27 Great George Street, Westminster, S.W.

1869. Browne, Benjamin Chapman, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.

1874. Browne, Tomyns Reginald, Assistant District Locomotive Superintendent, East Indian Railway, Allahabad, India: (or care of Messrs. B. Smyth and Co., 1 New China Bazaar Street, Calcutta.)

1869. Browne, Walter Raleigh, 23 Queen Anne's Gate, Westminster, S.W.

1874. Bruce, George Barclay, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1867. Bruce, William Duff, Vice-Chairman, Port Commission, Calcutta.

1873. Brunel, Henry Marc, 23 Delahay Street, Westminster, S.W.

1870. Brunlees, James, F.R.S.E., 5 Victoria Street, Westminster, S.W.

1884. Bryan, William B., Engineer, East London Water Works, Old Ford, London, E.

1873. Buckley, Robert Burton, Executive Engineer, Indian Public Works Department, Supreme Government, India: (or care of H. Burton Buckley, 1 St. Mary's Terrace, Paddington, London, W.)

1877. Buckley, Samuel, Messrs. Buckley and Taylor, Castle Iron Works, Oldham.

1874. Buddicom, William Barber, Penbedw Hall, Mold, Flintshire.

1872. Budenberg, Arnold, Messrs. Schaeffer and Budenberg, 1 Southgate, St. Mary's Street, Manchester.

1882. Budge, Enrique, Engineer-in-Chief, Harbour Works, Valparaiso, Chile.

1881. Bulkley, Henry Wheeler, 149 Broadway, New York.

1884. Bullock, Joseph Henry, General Manager, Pelsall Coal and Iron Works, near Walsall.

1882. Bulmer, John, Spring Garden Engineering Works, Pitt Street, Newcastle-on-Tyne.

1884. Bunning, Charles Ziethen, Assistant Mining Engineer of the Government Coal Mines, Warora, Central Provinces, India.

1884. Bunt, Thomas, Superintendent Engineer, Kiangnan Arsenal, Shanghai, China: (or care of R. Pearce, Lanarth House, Holders Hill, Hendon, London, N.W.)

1884. Bunting, George Albert, Assistant Mechanical Engineer, Rio Tinto Mines, Huelva, Spain.

1877. Burgess, James Fletcher, 11 Almeric Road, Clapham Junction, London, S.W.

1881. Burn, Robert Scott, Oak Lea, Edgeley Road, near Stockport.

1874. Burn, William Edward, 173 Portland Road, Newcastle-on-Tyne.

1878. Burnett, Robert Harvey, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1878. Burrell, Charles, Jun., Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford.

1877. Burton, Clerke, 22 Oakfield Street, Roath, Cardiff.

1870. Bury, William, 5 New London Street, London, E.C.

1884. Butcher, Joseph John, 4 St. Nicholas' Buildings, Newcastle-on-Tyne.

1882. Butler, Edmund, Kirkstall Forge, near Leeds.

1859. Butler, John, Stanningley Iron Works, near Leeds.

1877. Campbell, Angus, Superintendent of the Government Foundry and Workshops, Roorkee, India.

1880. Campbell, Daniel, Messrs. Campbell and Schultz, 90 Cannon Street, London, E.C.

1869. Campbell, James, Hunslet Engine Works, Leeds.

1882. Campbell, John, Messrs. R. W. Deacon and Co., Kalimaas Works, Soerabaya, Java.

1882. Campos, Raphael Martinez, 598 General Lavalle, Buenos Aires.

1860. Carbutt, Edward Hamer, M.P., 19 Hyde Park Gardens, London, W.

1878. Cardew, Cornelius Edward, Locomotive and Carriage Superintendent, State Railways Establishment, Public Works Department, Government of India: Elmley House, 33 Parkend Road, Gloucester: (or care of Rev. J. H. Cardew, Keynshambury House, Cheltenham.)

1875. Cardozo, Francisco Corrêa de Mesquita, Messrs. Cardozo and Irmâo, Pernambuco Engine Works, Pernambuco, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.) (*Life Member.*)

1878. Carlton, Thomas William, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C.; and 1 Canfield Gardens, Priory Road, West Hampstead, London, N.W.

1869. Carpmael, Frederick, 57 Arlingford Road, Tulse Hill Gardens, Brixton, London, S.W.

1866. Carpmael, William, 24 Southampton Buildings, London, W.C.

1877. Carr, Robert, Resident Engineer, London and St. Katharine Docks Co., London Docks, Upper East Smithfield, London, E.

1884. Carrick, Henry, Messrs. Carrick and Wardale, Redheugh Engine Works, Gateshead.

1874. Carrington, William T. H., 9 and 11 Fenchurch Avenue, London, E.C.

1877. Carter, Claude, Manager, Messrs. Hetherington and Co., Ancoats Works, Pollard Street, Manchester.

1877. Carter, William, Ingénieur-en-Chef, Société anonyme du Phœnix, Ghent, Belgium.

1870. Carver, James, Lace Machine Works, Alfred Street, Nottingham.

1883. Cawley, George, Assistant Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1876. Challen, Stephen William, Messrs. Taylor and Challen, Derwent Foundry, 99 Constitution Hill, Birmingham.

1884. Chamberlain, John, Assistant Engineer, Gas Light and Coke Co.'s Tar and Liquor Works, Beckton, London, E.

1882. Chapman, Hedley, Messrs. Chapman Carverhill and Co., Scotswood Road, Newcastle-on-Tyne.

1866. Chapman, Henry, 113 Victoria Street, Westminster, S.W.; and 10 Rue Laffitte, Paris.

1878. Chapman, James Gregson, Messrs. Fawcett Preston and Co., Phœnix Foundry, Liverpool; and 25 Austinfriars, London, E.C.

1877. Chater, John, Messrs. Henry Pooley and Son, 89 Fleet Street, London, E.C.

1872. Chatwin, Thomas, Victoria Works, Great Tindal Street, Ladywood, Birmingham.

1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton; and Irwell House, Drinkwater Park, Prestwich, near Manchester.

1873. Cheesman, William Talbot, Hartlepool Rope Works, Hartlepool.

1881. Chilcott, William Winsland, Devonport Dockyard, Devonport.

1883. Childe, Rowland, Mining Engineer, Stamp Office Place, Wakefield.

1877. Chisholm, John, Messrs. William Muir and Co., Sherborne Street, Manchester; and 30 Devonshire Street, Higher Broughton, Manchester.

1857. Chrimes, Richard, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1882. Church, Charles Simmons, Resident Engineer, Water Works, Barranquilla, United States of Colombia; and Chacewater Vicarage, Scorrier, Cornwall.

1880. Churchward, George Dundas, Box 717, General Post Office, Sydney, New South Wales; or care of A. W. Churchward, London Chatham and Dover Railway, Queenborough Pier, Queenborough; and Kersney Manor, Dover.

1871. Clark, Christopher Fisher, Mining Engineer, Garswood Coal and Iron Co., Park Lane Collieries, Wigan; and Cranbury Lodge, Park Lane, Wigan.

1878. Clark, Daniel Kinnear, 8 Buckingham Street, Adelphi, London, W.C.

1859. Clark, George, Southwick Engine Works, near Sunderland.

1867. Clark, George, Jun., Southwick Engine Works, near Sunderland.

1869. Clark, William, Mining Engineer, Teversall Collieries, near Mansfield.

1865. Clarke, John, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds.

1869. Clarke, William, Messrs. Clarke Chapman and Gurney, Victoria Works, South Shore, Gateshead.

1870. Clayton, Nathaniel, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.

1882. Clayton, William Wikeley, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds.

1871. Cleminson, James, 7 Westminster Chambers, Victoria Street, Westminster, S.W.

1873. Clench, Frederick, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1882. Coates, Joseph, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1883. Coath, David Decimus, Agricultural Implement Works and Saw Mill, Rangoon, British Burmah, India.

1881. Cochrane, Brodie, Mining Engineer, Aldin Grange, Durham.

1858. Cochrane, Charles, Woodside Iron Works, near Dudley; and The Grange, Stourbridge.

1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.

1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne; and Oakfield House, Gosforth, Newcastle-on-Tyne.

1867. Cockey, Francis Christopher, Selwood Iron Works, Frome.

1864. Coddington, William, Ordnance Cotton Mill, Blackburn.

1876. Coe, William John, 1 Rumford Place, Liverpool.

1847. Coke, Richard George, Mining Engineer, 39 Holywell Street, Chesterfield; and Brimington Hall, near Chesterfield.

1884. Cole, Charles, Messrs. Cole Marchent and Co., Prospect Foundry, Bowling, near Bradford.

1878. Cole, John William, Elm Cottage, Osmond Terrace, Norwood, Adelaide, South Australia: (or care of Messrs. James Sinton and Co., 7 St. Benet Place, Gracechurch Street, London, E.C.)

1878. Coles, Henry James, Sumner Street, Southwark, London, S.E.
1877. Coley, Henry, Mansion House Chambers, Queen Victoria Street, London, E.C.; and 10 Hopton Road, Coventry Park, Streatham, London, S.W.
1884. Collenette, Ralph, Hæmatite Iron and Steel Works, Barrow-in-Furness.
1884. Colquhoun, James, General Manager, Tredegar Iron Coal and Steel Works, Tredegar.
1884. Coltman, John Charles, Messrs. Huram Coltman and Son, Engineering Works, Meadow Lane, Loughborough.
1878. Colyer, Frederick, 18 Great George Street, Westminster, S.W.
1881. Compton-Bracebridge, John Edward, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.
1874. Conyers, William, Engineer, Bluff Harbor Board, Campbelltown, Otago, New Zealand.
1877. Cooper, Arthur, North Eastern Steel Co., Royal Exchange, Middlesbrough.
1883. Cooper, Charles Friend, Messrs. Paterson and Cooper, Telegraph Works, Pownall Road, Dalston, London, E.
1877. Cooper, George, Engineer and General Manager, Buenos Ayres Great Southern Railway, Buenos Ayres: (or care of Secretary, Buenos Ayres Great Southern Railway, 4 Great Winchester Street, London, E.C.)
1874. Cooper, William, Neptune Foundry, Hull.
1881. Coote, Arthur, Messrs. Andrew Leslie and Co., Hebburn, Newcastle-on-Tyne.
1881. Copeland, Charles John, Messrs. Westray Copeland and Co., Barrow-in-Furness.
1884. Corder, George Alexander, Chief Engineer, Chinese Naval Service, Amoy, China; care of Commissioner of Customs, Amoy, China.
1878. Cornes, Cornelius, 30 Walbrook, London, E.C.
1848. Corry, Edward, 8 New Broad Street, London, E.C.
1881. Cosser, Thomas, McLeod Road Iron Works, Kurrachee, India.
1875. Cotton, Francis Michael, 9 Victoria Chambers, Victoria Street, Westminster, S.W.; and 2 Courthope Villas, Wimbledon, Surrey.
1884. Cotton, John, Messrs. E. Ripley and Sons, Bowling Dye Works, Bradford.
1875. Cottrill, Robert Nivin, Beehive Works, Bolton.
1868. Coulson, William, Mining Engineer, 32 Crossgate, Durham; and Shamrock House, Durham.
1878. Courtney, Frank Stuart, 3 Whitehall Place, London, S.W.
1882. Courtney, William McDougall, 15 Elizabeth Terrace, Upper William Street North, Sydney, New South Wales.
1875. Coward, Edward, Messrs. Melland and Coward, Cotton Mills and Bleach Works, Heaton Mersey, near Manchester.
1875. Cowen, Edward Samuel, Messrs. G. R. Cowen and Co., Beck Foundry, Brook Street, Nottingham; and 9 Rope Walk Street, Nottingham.

1870. Cowen, George Roberts, Messrs. G. R. Cowen and Co., Beck Foundry, Brook Street, Nottingham; and 9 Rope Walk Street, Nottingham.

1880. Cowper, Charles Edward, 6 Great George Street, Westminster, S.W.

1847. Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.

1878. Coxhead, Frederick Carley, 27 Leadenhall Street, London, E.C.

1883. Crampton, George, 4 Victoria Street, Westminster, S.W.

1847. Crampton, Thomas Russell, 4 Victoria Street, Westminster, S.W.

1882. Craven, John, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1871. Craven, Joseph, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1866. Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.

1884. Crighton, John, Messrs. J. and R. Crighton, Helena Street, Ancoats, Manchester.

1873. Crippin, Edward Frederic, Mining Engineer, Brynn Hall Colliery, Ashton, near Wigan.

1883. Croft, Henry, Chemanns, Vancouver Island.

1878. Crohn, Frederick William, 16 Burney Street, Greenwich, S.E.

1877. Crompton, Rookes Evelyn Bell, Arc Works, Chelmsford; and Mansion House Buildings, Queen Victoria Street, London, E.C.

1884. Crook, Charles Alexander, Telegraph Construction and Maintenance Works, Enderby's Wharf, East Greenwich, London, S.E.

1883. Cropper, Henry S., Minerva Works, Alfred Street North, Nottingham.

1881. Crosland, James Foyell Lovelock, Chief Assistant Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1865. Cross, James, Messrs. John Hutchinson and Co., Alkali Works, Widnes; and Ditton Lodge, Warrington.

1882. Cross, William, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.

1871. Crossley, William, 153 Queen Street, Glasgow.

1875. Crossley, William John, Messrs. Crossley Brothers, Great Marlborough Street, Manchester.

1882. Cruickshank, William Douglass, Government Engineer Surveyor, 12 Custom House Buildings, Sydney, New South Wales.

1884. Cureton, Barnard John, Manager, Patent Nut and Bolt Works, Smethwick, near Birmingham.

1875. Curtis, Richard, Messrs. Curtis Sons and Co., Phœnix Works, Chapel Street, Manchester.

1876. Cutler, Samuel, Providence Iron Works, Millwall, London, E.

1879. Dady, Jamsetjee Nesserwanjee, 10 Dady Sett House, Fort, Bombay, India.

1864. Daglish, George Heaton, St. Helen's Foundry, St. Helen's, Lancashire.

1883. D'Albert, Charles, Messrs. Hotchkiss and Co., 6 Route de Gonesse, St. Denis, near Paris.

1881. D'Alton, Patrick Walter, London Mutual Boiler Insurance Co., 17 Queen Victoria Street, London, E.C.

866. Daniel, Edward Freer, Messrs. Worthington and Co., The Brewery, Burton-on-Trent; and 11 Needwood Street, Burton-on-Trent.

1866. Daniel, William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds; and Oxford House, Horsforth, Leeds.

1864. Darby, Charles E., Brymbo Iron Works, near Wrexham.

1879. Darling, William Littell, 87 Cromwell Road, South Kensington, London, S.W.

1878. Darwin, Horace, The Orchard, Huntingdon Road, Cambridge. (*Life Member.*)

1873. Davey, Henry, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds.

1883. Davidson, George, Superintendent Engineer, Australasian Steam Navigation Co., Sydney, New South Wales.

1865. Davidson, James, Royal Arsenal, Laboratory Department, Woolwich.

1881. Davidson, James, Engineering Works, Cumberland Street, Dunedin, Otago, New Zealand: (or care of Messrs. Buxton Ronald and Co., 24 Basinghall Street, London, E.C.)

1884. Davidson, James Young, Manager, Nagpur and Chhattisgarh, and Wardha Coal State Railways, Nagpur, Central Provinces, India; (or care of Messrs. H. S. King and Co., 45 Pall Mall, London, W.)

1884. Davies, Alfred Herbert, Eskell Chambers, Market Place, Nottingham.

1881. Davies, Benjamin, Bleach Works, Adlington, near Chorley.

1880. Davies, Charles Merson, Locomotive Superintendent, Holkar and Sindia-Neemuch State Railway, Khandwa, India.

1874. Davis, Alfred, Parliament Mansions, Westminster, S.W.

1868. Davis, Henry Wheeler, 11 New Broad Street, London, E.C.

1873. Davis, John Henry, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester; and 147 Cannon Street, London, E.C.

1877. Davison, John Walter, Moscow and Riazan Railway, Moscow, Russia: (or care of Alfred L. Sacré, 60 Queen Victoria Street, London, E.C.)

1884. Davison, Robert, Caledonian Railway, Locomotive Department, St. Rollox, Glasgow.

1873. Davy, David, Messrs. Davy Brothers, Park Iron Works, Sheffield.

1874. Davy, Walter Scott, Hæmatite Iron and Steel Works, Barrow-in-Furness.

1883. Daw, James Gilbert, Messrs. Nevill Druce and Co., Llanelly Copper Works, Llanelly.

1874. Daw, Samuel, Pearston House, 23 The Walk, Tredegarville, Cardiff.

1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.

1879. Dawson, Bernard, The Laurels, Malvern Link, Malvern.

1869. Day, St. John Vincent, 115 St. Vincent Street, Glasgow.

1874. Deacon, George Frederick, Municipal Offices, Dale Street, Liverpool.

1880. Deacon, Richard William, Boeboetan, Clive Road, Penarth.

1883. Dean, Francis Winthrop, 604 Main Street, Cambridgefort, Massachusetts, United States.

1868. Dean, William, Locomotive Superintendent, Great Western Railway, Swindon.

1866. Death, Ephraim, Messrs. Death and Ellwood, Albert Works, Leicester.

1884. Decauville, Paul, Portable Railway Works, Petit Bourg, Seine et Oise, France.

1877. Dees, James Gibson, 36 King Street, Whitehaven.

1858. Dempsey, William, 26 Great George Street, Westminster, S.W.

1882. Denison, Samuel, Jun., Messrs. Samuel Denison and Son, Old Grammar School Foundry, North Street, Leeds.

1883. Dennis, William Frederick, 101 Leadenhall Street, London, E.C.

1882. Denny, William, F.R.S.E., Messrs. William Denny and Sons, Leven Ship Yard, Dumbarton.

1880. De Pape, William Alfred Harry, Tottenham Board of Health, Coombes Croft House, High Road, Tottenham, Middlesex.

1883. Dick, Frank Wesley, Steel Company of Scotland, Blochairn Steel Works, Glasgow.

1882. Dick, Gavin Gemmell, 1 Westminster Chambers, Victoria Street, Westminster, S.W.

1880. Dickinson, John, Palmer's Hill Engine Works, Sunderland.

1875. Dickinson, William, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.

1879. Dickson, John, Willowbank, Darlington.

1883. Dixon, Samuel, Messrs. Kendall and Gent, Victoria Works, Springfield, Salford, Manchester.

1872. Dobson, Benjamin Alfred, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton.

1873. Dobson, Richard Joseph Caistor, Volharding Iron Works, Soerabaya, Java: (or care of Charles E. S. Dobson, 4 Chesterfield Buildings, Victoria Park, Clifton, Bristol.)

1880. Dodd, John, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1868. Dodman, Alfred, Highgate Foundry, Lynn.

1880. Donald, James, Messrs. Donald Henesey and Couper, Ripon Iron Works, Frere Road, Bombay: (or care of Messrs. Fleming Wilson and Co., 24, 25, 27 Rood Lane, Fenchurch Street, London, E.C.)

1876. Donaldson, John, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.; and Tower House, Turnham Green.

1873. Donkin, Bryan, Jun., Messrs. B. Donkin and Co., Blue Anchor Road, Bermondsey, London, S.E.

1884. Donnelly, John, Assistant Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.W.

1865. Douglas, Charles Prattman, Consett Iron Works, near Blackhill, County Durham; and Parliament Street, Consett, County Durham.

1879. Douglass, Sir James Nicholas, Engineer to the Trinity Board, Trinity House, London, E.C.

1879. Douglass, William, Chief Engineer to the Commissioners of Irish Lights, Westmoreland Street, Dublin.

1879. Doulton, Bernard, Lambeth Pottery, Lambeth, London, S.E.

1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Iron and Engine Works, Carlisle; and Viewfield, Stanwix, near Carlisle.

1873. Dove, George, Jun., Redbourn Hill Iron Works, Frodingham, near Doncaster.

1866. Downey, Alfred C., Messrs. Downey and Co., Coatham Iron Works, Middlesbrough; and Post Office Chambers, Middlesbrough.

1881. Dowson, Joseph Emerson, 3 Great Queen Street, Westminster, S.W.

1880. Doxford, Robert Pile, Messrs. William Doxford and Sons, Pallion Shipbuilding and Engine Works, Sunderland.

1874. Dredge, James, 35 Bedford Street, Strand, London, W.C.

1877. Dübs, Charles Ralph, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1877. Dübs, Henry John Sillars, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1880. Duckham, Frederic Eliot, Engineer, Millwall Docks, London, E.

1881. Duckham, Heber, 35 Queen Victoria Street, London, E.C.

1879. Duncan, David John Russell, Messrs. Duncan Brothers, 32 Queen Victoria Street, London, E.C.

1870. Dunlop, James Wilkie, 49 Albert Street, Regent's Park, London, N.W.

1881. Dunn, Henry Woodham, Knysna, Cape Colony.

1865. Dyson, Robert, Messrs. Owen and Dyson, Rother Iron Works, Rotherham.

1880. Eager, John Edward, Messrs. William Crichton and Co., Engineering and Shipbuilding Works, Abo, Finland.

1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.

1858. Easton, Edward, 11 Delahay Street, Westminster, S.W.

1867. Easton, James, Mining Engineer, Nest House, Gateshead.

1875. Eaves, William, Engineer, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.

1878. Eckart, William Roberts, Messrs. Salkeld and Eckart, 632 Market Street, P. O. Box 1587, San Francisco, California, United States.

1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1883. Edmiston, James Brown, Marine Superintending Engineer, Messrs. Hamilton Fraser and Co., K Exchange Buildings, Liverpool; and Ivy Cottage, Highfield Road, Walton, Liverpool.

1871. Edwards, Edgar James, Messrs. Morewood and Co., Woodford Iron Works, Soho, Birmingham.

1877. Edwards, Frederick, 62 Bishopsgate Street Within, London, E.C.

1880. Edwards, Robert, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.

1866. Elce, John, 9 Hopwood Avenue, Manchester.

1879. Ellacott, Robert Henry, Messrs. Ellacott and Co., Plymouth Foundry, Plymouth.

1875. Ellington, Edward Bayzand, Hydraulic Engineering Works, Chester; and Hydraulic Engineering Co., Palace Chambers, 9 Bridge Street, Westminster, S.W.

1859. Elliot, Sir George, Bart., M.P., Houghton-le-Spring, near Fence Houses.

1883. Elliott, Henry John, Assistant Manager, Elliott's Metal Works, Selly Oak, near Birmingham.

1869. Elliott, Henry Worton, Metal Sheathing Works, 10 Coleshill Street, Birmingham; and Selly Oak Works, near Birmingham.

1882. Elliott, Thomas Graham, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1880. Ellis, Oswald William, 26 George Street, Edinburgh.

1869. Elwell, Alfred, Edge Tool Works, Wood Green, Wednesbury.

1875. Elwell, Thomas, Messrs. Varrall Elwell and Middleton, 1 Avenue Trudaine, Paris.

1878. Elwin, Charles, Metropolitan Board of Works, Spring Gardens, London, S.W.

1884. Etherington, John, 39A King William Street, London Bridge, London, E.C.

1884. Evans, David, General Manager, Rhymney Iron Works, Rhymney, R.S.O., Monmouthshire.

1864. Everitt, William Edward, Messrs. Allen Everitt and Sons, Kingston Metal Works, Adderley Street, Birmingham; and Finstal, Bromsgrove.

1881. Ewen, Thomas Buttwell, Messrs. Tangye Brothers, Cornwall Works, Soho, near Birmingham.

1869. Faija, Henry, 4 Great Queen Street, Westminster, S.W.
1868. Fairbairn, Sir Andrew, M.P., Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds; and 15 Portman Square, London, W.
1875. Farcot, Jean Joseph Léon, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.
1880. Farcot, Paul, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.
1867. Fardon, Thomas, 106 Queen Victoria Street, London, E.C.; and 63 Collingdon Street, Luton.
1881. Farrar, Sidney Howard, Messrs. Howard Farrar and Co., Port Elizabeth, South Africa; and 69 Cornhill, London, E.C.
1882. Fawcett, Thomas Constantine, Burmantofts Foundry, Leeds.
1884. Fearfield, John Piggin, Lace Machine Works, Stapleford, near Nottingham.
1882. Feeny, Victor Isidore, 106 Queen Victoria Street, London, E.C.
1876. Fell, John Corry, 1 Queen Victoria Street, London, E.C.; and Excelsior Works, Old Street, London, E.C.
1877. Fenton, James, 8 Great George Street, Westminster, S.W.
1869. Fenwick, Clennell, Victoria Docks Engine Works, Victoria Docks, London, E.
1870. Ferguson, Henry Tanner, Locomotive Superintendent, Punjaub Northern State Railway, Rawal Pindi, Punjaub, India.
1881. Ferguson, William, Harbour Board, Wellington, New Zealand: (or care of Montgomery Ferguson, 81 James Street, Dublin.)
1854. Fernie, John, P.O. Box 57, Philadelphia, Pennsylvania, United States.
1866. Fiddes, Walter, Engineer, Bristol United Gas Works, Bristol.
1872. Fidler, Edward, Prescot Colliery, Prescot.
1867. Field, Edward, Chandos Chambers, 22 Buckingham Street, Adelphi, London, W.C.
1861. Field, Joshua, 110 Westminster Bridge Road, Lambeth, London, S.E.
1884. Fielden, Joseph Petrie, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.
1874. Fielding, John, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester.
1865. Filliter, Edward, 16 East Parade, Leeds.
1884. Fisher, Henry Oakden, Engineer, Taff Vale Railway, Cardiff.
1877. Flannery, James Fortescue, 9 Fenchurch Street, London, E.C.
1864. Fleet, Thomas, Crown Boiler and Gasholder Works, Swan Village, Westbromwich.
1882. Fletcher, David Hardman, Messrs. W. Collier and Co., Worsley Street, New Bailey Street, Salford, Manchester.

1847. Fletcher, Edward, 2 Osborne Avenue, West Jesmond, Newcastle-on-Tyne.

1883. Fletcher, George, Masson Works, Derby.

1858. Fletcher, Henry Allason, Messrs. Fletcher Jennings and Co., Lowca Engine Works, Whitehaven. (*Life Member.*)

1872. Fletcher, Herbert, Ladyshore Colliery, Little Lever, Bolton; and The Hollins, Bolton.

1867. Fletcher, Lavington Evans, Chief Engineer, Manchester Steam Users' Association, 9 Mount Street, Albert Square, Manchester.

1872. Flower, James J. A., Messrs. James Flower and Sons, St. Mary's Chambers, St. Mary Axe, London, E.C.

1859. Fogg, Robert, 11 Queen Anne's Gate, Westminster, S.W.

1878. Fontaine, Marc Berrier-, Ingénieur de la Marine, Toulon Dockyard, Toulon, France: (or care of Messrs. P. S. King and Son, Canada Buildings, King Street, Westminster, S.W.)

1877. Forbes, Daniel Walker, Smithfield Works, New Road, Blackwall, London, E.

1882. Forbes, David Moncur, Engineer, H. M. Mint, Calcutta.

1882. Forbes, William George Loudon Stuart, Superintendent of General Workshops, H. M. Mint, Calcutta.

1861. Forster, Edward, Messrs. Chance Brothers and Co., Glass Works, Spon Lane, near Birmingham.

1882. Forsyth, Robert Alexander, 28 Tunnel Terrace, Newport, Monmouthshire.

1884. Foster, John Slater, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1882. Fothergill, John Reed, Superintendent Marine Engineer, 1 Bathgate Terrace, West Hartlepool.

1877. Foulis, William, Engineer, Glasgow Corporation Gas Works, 42 Virginia Street, Glasgow.

1866. Fowler, George, Mining Engineer, Basford Hall, near Nottingham.

1847. Fowler, John, 2 Queen Square Place, Westminster, S.W.

1866. Fox, Charles Douglas, 5 Delahay Street, Westminster, S.W.

1884. Fox, Frederick George Brook, Executive Engineer, Public Works Department, Drainage Embankment and Water Works, Prome, British Burmah, India.

1875. Fox, Samson, Leeds Forge, Leeds.

1882. Fox, William, Leeds Forge, Leeds.

1884. Frampton, Edwin, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E.

1877. Fraser, John Hazell, Messrs. Fraser Brothers, Railway Iron Works, Bromley, London, E.

1876. Frost, William, Manager, Carlisle Steel and Engine Works, Sheffield; and Woodhill, Sheffield.

1866. Fry, Albert, Bristol Wagon Works, Lawrence Hill, Bristol.

1884. Furness, Edward, 66 Finsbury Pavement, London, E.C.

1882. Furrell, Edward Wyburd, London Joint Stock Bank Chambers, 124 Chancery Lane, London, W.C.

1866. Galloway, Charles John, Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester.

1862. Galton, Capt. Douglas, C.B., R.E., F.R.S., 12 Chester Street, Grosvenor Place, London, S.W.

1880. Galwey, John Wilfrid de Villemont, Messrs. Galwey Whitehead and Co., Warrington Engine and Iron Works, Lythgoe's Lane, Warrington.

1884. Ganga Ram, Lala, Executive Engineer, Public Works Department, Amritsar, Punjaub, India.

1882. Garrett, Frank, Messrs. Richard Garrett and Sons, Leiston Works, Leiston, R.S.O., Suffolk.

1882. Garrett, Richard, Messrs. Richard Garrett and Sons, Leiston Works, Leiston, R.S.O., Suffolk.

1867. Gauntlett, William Henry, 33 Albert Terrace, Middlesbrough.

1880. Geoghegan, Samuel, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.

1871. Gibbins, Richard Cadbury, Berkley Street, Birmingham.

1872. Gilbert, Ebenezer Edwin, Canada Engine Works, Montreal, Canada.

1883. Gilchrist, Percy Carlyle, 2 Wellington Place, Penn Fields, Wolverhampton.

1856. Gilkes, Edgar, Messrs. Thompson and Gilkes, Stockton-on-Tees; and Broad Green House, Norton, Stockton-on-Tees.

1880. Gill, Charles, Messrs. Young and Gill, Engineering Works, Java; and Java Lodge, Beckenham.

1866. Gilroy, George, Engineer, Ince Hall Colliery, Wigan.

1884. Gimson, Arthur James, Messrs. Gimson and Co., Engine Works, Vulcan Street, Leicester.

1884. Girdlestone, John Ward, Engineer, Bristol Docks, Bristol.

1881. Girdwood, William Wallace, Indestructible Packing Works, 9 Lea Place, East India Dock Road, Poplar, London, E.

1874. Gjers, John, Messrs. Gjers Mills and Co., Ayresome Iron Works, Middlesbrough.

1862. Godfrey, Samuel, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough; and Beaconsfield House, North Ormesby, Middlesbrough.

1880. Godfrey, William Bernard, 54 Regent's Park Road, Regent's Park, London, N.W.

1882. Goldsmith, Alfred Joseph, Messrs. John Walker and Co., Union Foundry and Shipbuilding Works, Maryborough, Queensland.

1879. Goldsworthy, Robert Bruce, Messrs. Thomas Goldsworthy and Sons, Britannia Emery Mills, Hulme, Manchester.

1867. Gooch, William Frederick, Vulcan Foundry, Newton-le-Willows, Lancashire.

1877. Goodbody, Robert, Messrs. Goodbody, Clashawaun Jute Factory, Clara, near Moate, Ireland.

1869. Goodeve, Thomas Minchin, 5 Crown Office Row, Temple, London, E.C.

1875. Goodfellow, George Ben, Hyde Iron Works, Hyde, near Manchester.

1884. Goodger, Walter William, Messrs. Handyside and Co., Derby.

1865. Göransson, Göran Fredrick, Sandvik Iron Works, near Gefle, Sweden: (or care of F. W. Lonergan, 121 Cannon Street, London, E.C.)

1875. Gordon, Robert, Executive Engineer, Public Works Department, Henzada, British Burmah, India; and 74 Elgin Crescent, Notting Hill, London, W.: (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)

1879. Gorman, William Augustus, Messrs. Siebe and Gorman, 187 Westminster Bridge Road, London, S.E.

1880. Gottschalk, Alexandre, 13 Rue Auber, Paris.

1877. Goulty, Wallis Rivers, Messrs. Wheatley Kirk, Price, and Goutly, Albert Chambers, Albert Square, Manchester.

1878. Grafton, Alexander, 113 Cannon Street, London, E.C.

1865. Gray, John McFarlane, Chief Examiner of Engineers, Marine Department, Board of Trade; 86 Osborn Road, Forest Gate, London, E.

1876. Gray, John William, Engineer, Corporation Water Works, Broad Street, Birmingham.

1879. Gray, Thomas Lowe, Rokesley House, St. Michael's Road, Stockwell, London, S.W.

1879. Greathead, James Henry, 8 Victoria Chambers, Victoria Street, Westminster, S.W.

1861. Green, Edward, Messrs. E. Green and Son, Phœnix Works, Wakefield.

1871. Greener, John Henry, 14 St. Swithin's Lane, London, E.C.

1878. Greenwood, Arthur, Messrs. Greenwood and Batley, Albion Works, Leeds.

1874. Greenwood, William Henry, Professor of Metallurgy and Mechanical Engineering, Firth College, Sheffield.

1865. Greig, David, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1880. Gresham, James, Messrs. Gresham and Craven, Craven Iron Works, Ordsal Lane, Salford, Manchester.

1883. Grew, Frederick, 12 Stockleigh Road, St. Leonard's-on-Sea.

1874. Grew, Nathaniel, Dashwood House, 9 New Broad Street, London, E.C.

1866. Grice, Edwin James, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1868. Grierson, Henry Houldsworth, Moss Brow, Warburton, near Warrington.

1884. Griffiths, James E., Mount Stuart Square, Cardiff.

1873. Griffiths, John Alfred, 9 White Street, Coventry.

1879. Grose, Arthur, Manager, Vulcan Iron Works, Guildhall Road, Northampton.

1870. Guilford, Francis Leaver, Messrs. G. R. Cowen and Co., Beck Foundry, Brook Street, Nottingham.

1883. Guinotte, Lucien, Mariemont and Bascoup Collieries, Mariemont, Belgium.

1884. Gulland, James Ker, Diamond Drill Co., 6A Victoria Street, Westminster, S.W.

1870. Gwynne, James Eglinton Anderson, Essex Street Works, Strand, London, W.C. (*Life Member.*)

1870. Gwynne, John, Hammersmith Iron Works, Hammersmith, London, W.

1879. Hadfield, Robert, Hadfield Steel Foundry Co., Attercliffe, Sheffield.

1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.

1884. Hall, Albert Francis, George F. Blake Manufacturing Co., 44 Washington Street, Boston; and 3 Cordis Street, Charlestown, Boston, Massachusetts, United States.

1879. Hall, John Francis, Messrs. W. Jessop and Sons, Brightside Steel Works, Sheffield.

1881. Hall, John Percy, Engine Works Department, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow.

1882. Hall, John Willim, Foundry and Engine Works, Blaydon-on-Tyne, R.S.O., County Durham.

1874. Hall, Thomas Bernard, Patent Nut and Bolt Works, Smethwick, near Birmingham; and Ingleside, Sandon Road, Edgbaston, Birmingham.

1871. Hall, William Silver, Messrs. Hall and Clarke, Canal Street Iron Works, Derby; and 39 Hartington Street, Derby.

1880. Hallett, John Harry, 120 Powell's Place, Bute Docks, Cardiff.

1871. Halpin, Druitt, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1870. Hamand, Arthur Samuel, 9 Bridge Street, Westminster, S.W.

1875. Hammond, Walter John, Resident Engineer and Locomotive Superintendent, Paulista Railway, Campinas, São Paulo, Brazil; and 91 High Street, Ashford, Kent: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1870. Hannah, Joseph Edward, Liverpool Corporation Water Works, Llanforda Offices, Oswestry.

1874. Harding, William Bishop, IX. Bez., Uellöerstrasse Nr. 35, Budapest, Hungary.

1881. Hardingham, George Gatton Melhuish, 191 Fleet Street, London, E.C.

1883. Hardy, John George, Vacuum Brake Co., 7 Hohenstaufengasse, Vienna.

1869. Harfield, William Horatio, Mansion House Buildings, Queen Victoria Street, London, E.C.

1884. Harker, Harold Hayes, Locomotive Superintendent, Minas and Rio Railway, Cruzeiro, Rio de Janeiro, Brazil.

1873. Harman, Harry Jones, 100 King Street, Manchester.

1879. Harris, Henry Graham, 5 Great George Street, Westminster, S.W.

1873. Harris, Richard Henry, 63 Queen Victoria Street, London, E.C.

1877. Harris, William Wallington, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.; and 24 Alexandra Villas, Hornsey Park, London, N.

1858. Harrison, Thomas Elliot, Engineer-in-Chief, North Eastern Railway, Newcastle-on-Tyne.

1865. Harrison, William Arthur, Messrs. Allen Harrison and Co., Cambridge Street Works, Manchester.

1883. Hart, Frederick, Pottstown, Montgomery County, Pennsylvania, United States: (or care of A. Pye-Smith, Messrs. Samuel Osborn and Co., 16 Philpot Lane, London, E.C.)

1877. Hart, James, 138 Portland Street, Southport.

1882. Hart, Norman, 54 Tressillian Road, St. John's, London, S.E.

1872. Hartnell, Wilson, Benson's Buildings, Park Row, Leeds.

1882. Harvey, Charles Randolph, Messrs. G. and A. Harvey, Albion Machine Works, Govan, near Glasgow.

1883. Harvey, Robert, Messrs. North and Harvey, Liverpool Nitrate Works, Iquique, Chile.

1878. Harwood, Robert, Soho Iron Works, Bolton.

1882. Haskins, John Ferguson, 114A Queen Victoria Street, London, E.C.

1881. Haslam, Alfred Seale, Union Foundry, Derby.

1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.

1857. Haughton, S. Wilfred, Greenbank, Carlow, Ireland. (*Life Member.*)

1878. Haughton, Thomas, 110 Cannon Street, London, E.C.

1861. Hawkins, William Bailey, 2 Suffolk Lane, Cannon Street, London, E.C.

1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.

1856. Hawksley, Thomas, F.R.S., 30 Great George Street, Westminster, S.W.

1873. Hay, James A. C., Superintendent of Machinery to the War Department, Royal Arsenal, Woolwich.

1882. Hayes, Edward, Watling Works, Stony Stratford.

1879. Hayes, John, 27 Leadenhall Street, London, E.C.

1862. Haynes, Thomas John, Calpe Foundry and Forge, North Front, Gibraltar.

1880. Hayter, Harrison, 33 Great George Street, Westminster, S.W.

1869. Head, Jeremiah, Messrs. Fox Head and Co., Newport Rolling Mills, Middlesbrough.

1873. Headly, Lawrance, 1 Camden Place, Cambridge.

1857. Healey, Edward Charles, 163 Strand, London, W.C.

1872. Heap, William, 9 Rumford Place, Liverpool.

1864. Heathfield, Richard, Messrs. Morewood and Co., Lion Galvanising Works, Birmingham Heath, Birmingham.

1878. Hedges, Killingworth William, 25 Queen Anne's Gate, Westminster, S.W.

1875. Heenan, Richard Hammersley, Messrs. Heenan and Froude, Newton Heath Iron Works, near Manchester.

1879. Henchman, Humphrey, care of John Henchman, Uplands, Wallington, Surrey.

1869. Henderson, David Marr, Engineer-in-Chief, Imperial Maritime Customs Service of China, Shanghai, China; and Gattaway, Abernethy, Newburgh, Fife.

1883. Henderson, John Baillie, Engineer to the Queensland Government, Water Supply Department, Brisbane, Queensland.

1878. Henesey, Richard, Messrs. Donald Henesey and Couper, Ripon Iron Works, Frere Road, Bombay.

1879. Henriques, Cecil Quixam, Parliament Mansions, Westminster, S.W.

1875. Hepburn, George, Redcross Chambers, Redcross Street, Liverpool.

1876. Heppell, Thomas, Mining Engineer, Ouston Collieries, Chester-le-Street.

1877. Hepworth, Thomas Howard, Curzon House, Curzon Street, Derby.

1884. Hernu, Arthur Henry, 35 Bedford Street, Strand, London, W.C.

1884. Hervey, Matthew Wilson, Assistant Engineer, West Middlesex Water Works, Hammersmith, London, W.

1879. Hesketh, Everard, Messrs. J. and E. Hall, Iron Works, Dartford.

1865. Hetherington, John Muir, Vulcan Works, Pollard Street, Manchester.

1866. Hetherington, Thomas Ridley, Vulcan Works, Pollard Street, Manchester.

1865. Hewett, Edward Edwards, High Court, High Street, Sheffield.

1872. Hewlett, Alfred, Haseley Manor, Warwick.

1872. Hewlett, William Henry, Wigan Coal and Iron Works, Kirkless Hall, Wigan.

1871. Hick, John, M.P., Mytton Hall, Whalley, near Blackburn.

1864. Hide, Thomas C., 4 Cullum Street, Fenchurch Street, London, E.C.

1879. Higson, Jacob, Mining Engineer, Crown Buildings, 18 Booth Street, Manchester.

1871. Hill, Alfred C., Clay Lane Iron Works, South Bank, R.S.O., Yorkshire.

1882. Hiller, Henry, Chief Engineer, National Boiler Insurance Company, 22 St. Ann's Square, Manchester.

1873. Hilton, Franklin, Chief Engineer, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough: and South Bank, R.S.O., Yorkshire.

1876. Hind, Thomas William, Messrs. Henry Hind and Son, Central Engineering Tool Works, Queen's Road, Nottingham; and 62 Blackfriars Road, London, S.E.

1870. Hodges, Petronius, 171 Burngreave Road, Sheffield.

1880. Hodgson, Charles, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W.

1882. Hodson, Richard, Thames Iron Works and Shipbuilding Co., Blackwall, London, E.

1884. Hogg, William Thomas, Ram Brewery, Wandsworth, London, S.W.

1852. Holcroft, James, Red Hill House, Stourbridge.

1866. Holcroft, Thomas, Bilston Foundry, Bilston.

1884. Holland, Calvert Bernard, General Manager, Ebbw Vale Coal Iron and Steel Works, Ebbw Vale, R.S.O., Monmouthshire.

1865. Holliday, John, Messrs. John Bethell and Co., Creosote Works, Westbromwich; and Oakfield Lodge, Booth Street, Handsworth, Birmingham.

1883. Holroyd, John, Tomlinson Street, Hulme, Manchester.

1863. Holt, Francis, Midland Railway, Locomotive Department, Derby.

1873. Holt, Henry Percy, Fairlea, Palatine Road, Didsbury, Manchester.

1867. Holt, William Lyster, 17 Parliament Street, Westminster, S.W.

1867. Homer, Charles James, Mining Engineer, Ivy House, Stoke-upon-Trent.

1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.

1883. Hooton, William, Continental Lace-Machine Works, Great Eastern Street, Nottingham.

1866. Hopkins, John Satchell, Jesmond Grove, Highfield Road, Edgbaston, Birmingham.

1856. Hopkinson, John, Grove House, Oxford Road, Manchester.

1874. Hopkinson, John, Jun., D.Sc., F.R.S., Lighthouse Department, Messrs. Chance Brothers and Co., Spon Lane, near Birmingham; and 4 Westminster Chambers, Victoria Street, Westminster, S.W.

1877. Hopkinson, Joseph, Messrs. Joseph Hopkinson and Co., Britannia Works, Huddersfield.

1867. Hopper, William, Machine Works, Moscow: (or care of Thomas Hopper, 18 Ann Street, Edinburgh.)

1880. Hornsby, James, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.

1873. Horsley, Charles, 22 Wharf Road, City Road, London, N.

1868. Horsley, Thomas, King's Newton, near Derby.

1858. Horsley, William, Whitehill Point Iron Works, Percy Main, near Newcastle-on-Tyne.

1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury.

1871. Horton, George, Messrs. Horton and Son, Steam Boiler Works, 63 Park Street, Southwark, London, S.E.

1875. Hosgood, Thomas Hopkin, Richardson Street, Swansea.

1873. Hoskin, Richard, 1 East Parade, Sheffield.

1866. Houghton, John Campbell Arthur, Woodside Iron Works, near Dudley.

1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1860. Howard, James, M.P., Messrs. J. and F. Howard, Britannia Iron Works, Bedford; and Clapham Park, Bedfordshire.

1882. Howard, John William, 78 Queen Victoria Street, London, E.C.

1867. Howard, Robert Luke, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1861. Howell, Joseph Bennett, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield.

1877. Howell, Samuel Earnshaw, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield.

1882. Howl, Edmund, Messrs. Lee Howl Ward and Howl, Tipton.

1877. Howlett, Francis, Messrs. Henry Clayton Son and Howlett, Atlas Works, Woodfield Road, Harrow Road, London, W.

1884. Hoyle, Frank Edward, Locomotive Superintendent, Bahia and San Francisco Railway, Periperi, Bahia, Brazil: (or care of Leonard Micklem, Secretary, Bahia and San Francisco Railway, 38 New Broad Street, London, E.C.)

1882. Hudson, John George, Messrs. Mirrlees Watson and Co., 45 Scotland Street, Glasgow.

1884. Hudson, Robert, Gildersome Foundry, near Leeds.

1881. Hughes, Edward William Mackenzie, Locomotive and Carriage Superintendent, Indus Valley State Railway, Sukkur, Sindh, India: (or care of Charles William Lennox, 7 Finlayson Place, Kelvinside, N., Glasgow.)

1867. Hughes, George Douglas, Queen's Foundry, London Road, Nottingham.

1871. Hughes, Joseph, General Manager, Lowca Engineering Co., Lowca Engine Works, near Whitehaven; and Moresby, near Whitehaven.

1864. Hulse, William Wilson, Ordsal Tool Works, Regent Bridge, Salford, Manchester.

1880. Humphrys, James, 16 and 17 Leadenhall Buildings, London, E.C.; and Arundel House, Lancaster Road, South Norwood Park, London, S.E.

1866. Humphrys, Robert Harry, Messrs. Humphrys Tennant and Co., Deptford Pier, London, S.E.

1882. Hunt, Reuben, Aire and Calder Chemical Works, Castleford, near Normanton.

1856. Hunt, Thomas, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1874. Hunt, William, Alkali Works, Lea Brook, Wednesbury; Hampton House, Wednesbury; and Aire and Calder Chemical Works, Castleford, near Normanton.

1877. Hunter, Walter, Messrs. Hunter and English, High Street, Bow, London, E.

1865. Hyde, Major-General Henry, R.E., India Office, Westminster, S.W. (*Life Member.*)

1877. Imray, John, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C.

1882. Ingham, William, 22 St. Ann's Square, Manchester.

1872. Inman, Charles Arthur, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead; and 45 North Corridor, The Albany, Liverpool.

1883. Instone, Thomas, Assistant Manager and Engineer, Elliott's Metal Works, Selly Oak, near Birmingham; and Harborne, near Birmingham.

1872. Jack, Alexander, Messrs. James Jack and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.

1884. Jacks, Thomas William Moseley, Assistant Manager, Patent Shaft Works, Wednesbury; and Portway Road, Wednesbury.

1876. Jackson, Henry James, Superintending Engineer, General Steam Navigation Co.'s Works, Deptford, London, S.E.

1859. Jackson, Matthew Murray, care of Messrs. Howard and Pitcairn, 155 Fenchurch Street, London, E.C.

1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester; and Blackbrooke, Pontrilas, R.S.O., Herefordshire.

1873. Jackson, Samuel, C.I.E., Locomotive and Carriage Superintendent, Great Indian Peninsula Railway, Bombay.

1872. Jackson, William Francis, Bowling Iron Works, near Bradford.

1873. Jacob, Edward Westley, Tees Side Iron and Engine Works, Middlesbrough; and 75 Grange Road West, Middlesbrough.

1876. Jacobs, Charles Mattathias, 126 Bute Docks, Cardiff.

1878. Jakeman, Christopher John Wallace, Manager, Messrs. Merryweather and Sons, Tram Locomotive Works, Greenwich Road, London, S.E.

1877. James, Christopher, 4 Alexandra Road, Clifton, Bristol.

1877. James, John William Henry, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1879. Jameson, George, Glencormac, Bray, Ireland.

1881. Jameson, John, Messrs. Jameson and Schaeffer, Akenside Hill, Newcastle-on-Tyne.

1882. Jardine, John, Lace Machine Works, Raleigh Street, Nottingham.

1876. Jebb, George Robert, Engineer to the Birmingham Canal Navigation, Birmingham; and The Laurels, Shrewsbury.

1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.

1880. Jefferies, John Robert, Messrs. Ransomes Head and Jefferies, Orwell Works, Ipswich.

1881. Jefferiss, Thomas, Messrs. Tangye Brothers, Cornwall Works, Soho, near Birmingham.

1863. Jeffreys, Edward A., Monk Bridge Iron Works, Leeds; and Gipton Lodge, Leeds.

1877. Jeffreys, Edward Homer, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1876. Jemson, James, 7 Ashton Terrace, Preston.

1875. Jenkin, H. C. Fleeming, F.R.S., Professor of Engineering, University of Edinburgh; 3 Great Stuart Street, Edinburgh.

1884. Jenkins, Alfred, Bridge Wharf Foundry, Abergavenny.

1878. Jensen, Peter, Messrs. Brewer and Jensen, 33 Chancery Lane, London, W.C.

1854. Jobson, John, Derwent Foundry, Derby.

1863. Johnson, Bryan, Hydraulic Engineering Works, Chester; and 34 King Street, Chester.

1882. Johnson, Charles Malcolm, Chief Engineer, R.N., H. M. Ironclad "Swiftsure," Esquimalt, Vancouver Island; and 11 Napier Street, Stoke, Devonport.

1882. Johnson, Samuel, Manager, Globe Cotton and Woollen Machine Works, Rochdale.

1861. Johnson, Samuel Waite, Locomotive Superintendent, Midland Railway, Derby.

1872. Joicey, Jacob Gowland, Messrs. J. and G. Joicey and Co., Forth Banks West Factory, Newcastle-on-Tyne.

1882. Jolin, Philip, 35 Narrow Wine Street, Bristol; and 2 Elmdale Road, Redland, Bristol.

1871. Jones, Charles Henry, Assistant Locomotive Superintendent, Midland Railway, Derby.

1873. Jones, Edward, Messrs. Greenwood and Batley, Albion Works, Leeds; and 2 Westhill Terrace, Chapel Allerton, Leeds.

1873. Jones, Edward Trygarn, Consulting Engineer to the Commercial Steam Ship Co., 32 Great St. Helen's, London, E.C.

1884. Jones, Felix, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1878. Jones, Frederick Robert, Superintending Engineer, Sirmoor State, Nahan, near Umballa, Punjaub, India: (or care of Messrs. Richard W. Jones and Co., Newport, Monmouthshire.)

1867. Jones, George Edward, Sakkur, near Karachi, Punjaub, India: (or care of Mrs. Edward Jones, 9 Sydenham Villas, Cheltenham.)

1878. Jones, Harry Edward, Engineer, Commercial Gas Works, Stepney, London, E.

1881. Jones, Herbert Edward, Locomotive Department, Midland Railway, Manchester.

1882. Jones, Samuel Gilbert, Bombay Burmah Trading Corporation, Rangoon, British Burmah: (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1872. Jones, William Richard Sumption, Rajputana State Railway, Ajmeer, India: (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)

1883. Jordan, Edward, Manager, Cardiff Junction Dry Dock and Engineering Works, Cardiff.

1884. Josse, Hippolyte, 15 Rue Drouot, Paris.

1880. Joy, David, 8 Victoria Chambers, Victoria Street, Westminster, S.W.; and 32 Anerley Park, Anerley, London, S.E.

1878. Jüngermann, Carl, Märkisch Schlesische Maschinenbau und Hütten Actien Gesellschaft, 3 Chaussée Strasse, Berlin.

1884. Justice, Howard Rudulph, 55 and 56 Chancery Lane, London, W.C.

1882. Keeling, Herbert Howard, Merlewood, Eltham.

1869. Keen, Arthur, Patent Nut and Bolt Works, Smethwick, near Birmingham.

1867. Kellett, John, Clayton Street, Wigan.

1873. Kelson, Frederick Colthurst, Angra Bank, Waterloo Park, Waterloo, near Liverpool.

1881. Kendal, Ramsey, Locomotive Department, North Eastern Railway, Gateshead.

1863. Kennan, James, Messrs. Kennan and Sons, Engineering Works, Fishamble Street, Dublin.

1879. Kennedy, Alexander Blackie William, Professor of Engineering, University College, Gower Street, London, W.C.

1847. Kennedy, James, Cressington Park, Aigburth, Liverpool.

1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway, 45 Finsbury Circus, London, E.C.; and 29 Lupus Street, St. George's Square, London, S.W.

1868. Kennedy, Thomas Stuart, Meanwood, near Leeds.

1875. Kenrick, George Hamilton, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich; and Maple Bank, Church Road, Edgbaston, Birmingham.

1884. Kerr, James, Messrs. Kerr Stuart and Co., 20 Bucklersbury, London, E.C.

1866. Kershaw, John, 9 Duke Street, Portland Place, London, W.

1884. Kershaw, Thomas Edward, Chilvers Coton Foundry, Nuneaton.

1880. Kessler, Emil, Maschinenfabrik, Esslingen, Wurtemberg, Germany.

1872. King, William, Engineer, Liverpool United Gas Works, Duke Street, Liverpool.

1872. Kirk, Alexander Carnegie, Messrs. Robert Napier and Sons, Lancefield House, Glasgow; and Govan Park, Govan, Glasgow.

1877. Kirk, Henry, Messrs. Kirk Brothers and Co., New Yard Iron Works, Workington.

1884. Kirkaldy, John, 40 West India Dock Road, London, E.

1875. Kirkwood, James, Chief Inspector of Machinery for Pei Yang Squadron; care of Imperial Maritime Customs, Chefoo, China.

1882. Kirkwood, Thomas, Harbour Engineer, Hong Kong and Whampoa Dock Co., Hong Kong, China.

1864. Kirtley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W.

1859. Kitson, James, Jun., Monk Bridge Iron Works, Leeds.

1868. Kitson, John Hawthorn, Airedale Foundry, Leeds.

1874. Klein, Thorvald, 46 Cannon Street, London, E.C.

1877. Kortright, Lawrence Moore, Superintendent of Public Works, St. Kitts, West Indies: (or care of G. D. Kortright, Plas Teg, near Mold, Flintshire.)

1881. Laing, Arthur, Deptford Shipbuilding Yard, Sunderland.

1872. Laird, Henry Hyndman, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.

1872. Laird, William, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.

1883. Lake, William Robert, 8 Southampton Buildings, London, W.C.

1873. Lamb, William James, Newtown and Meadows Collieries, near Wigan.

1878. Lambourn, Thomas William, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich.

1863. Lancaster, John, Bilton Grange, Rugby.

1881. Langdon, William, Locomotive Superintendent and Chief Mechanical Engineer, Rio Tinto Railway and Mines, Huelva, Spain: (or care of William G. Parsons, 11 Queen Victoria Street, London, E.C.)

1881. Lange, Frederick Montague Townshend, Messrs. Lange's Wool-Combing Works, Saint Acheul-les-Amiens, Somme, France.

1877. Lange, Hermann Ludwig, Manager, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1879. Langley, Alfred Andrew, Engineer-in-Chief, Midland Railway, Derby.

1879. Lapage, Richard Herbert, 13A Great George Street, Westminster, S.W.; and Craigleith, Surbiton.

1879. Larsen, Jorgen Daniel, 10 Delahay Street, Westminster, S.W.

1881. Lavalley, Alexander, 48 Rue de Provence, Paris.

1867. Lawrence, Henry, The Grange Iron Works, Durham.

1874. Laws, William George, Borough Engineer and Town Surveyor, Town Hall, Newcastle-on-Tyne; and 5 Winchester Terrace, Newcastle-on-Tyne.

1882. Lawson, Frederick William, Messrs. Samuel Lawson and Sons, Hope Foundry, Leeds.

1870. Layborn, Daniel, Messrs. Caine and Layborn, Dutton Street, Liverpool.

1856. Laybourne, Richard, Isca Foundry, Newport, Monmouthshire.

1883. Laycock, William S., Messrs. Samuel Laycock and Sons, Horse-hair Cloth Works, Sheffield; and Ranmoor, Sheffield.

1860. Lea, Henry, 38 Bennett's Hill, Birmingham.

1884. Leake, Arthur Hill, Sugar Engineer, Post Office, Brisbane, Queensland; (or care of Henry I. Wenham, 43 Finsbury Circus, London, E.C.)

1883. Leavitt, Erasmus Darwin, Jun., 604 Main Street, Cambridgeport, Massachusetts, United States.

1865. Ledger, Joseph, Keswick.

1862. Lee, J. C. Frank, 22 Great George Street, Westminster, S.W.

1871. Lee, William, Messrs. Lee Clerk and Robinson, Gospel Oak Iron Works, Tipton; and 110 Cannon Street, London, E.C.

1863. Lees, Samuel, Messrs. H. Lees and Sons, Park Bridge Iron Works, Ashton-under-Lyne.

1883. Lennox, John, 2 Victoria Mansions, Victoria Street, Westminster, S.W.

1882. Léon, Auguste, Locomotive Engineer, Chemins de fer de Paris à Lyon et à la Méditerranée, 220 Boulevard Voltaire, Paris.

1858. Leslie, Andrew, Iron Shipbuilding Yard, Hebburn, Newcastle-on-Tyne.

1883. Leslie, Joseph, Marine Engineer, Messrs. Apcar and Co., Raddah Bazar, Calcutta.

1878. Lewis, Gilbert, Manager, New Bridge Foundry, Adelphi Street, Salford, Manchester.

1884. Lewis, Henry Watkin, Bute Shipbuilding and Engineering Works, Cardiff.

1872. Lewis, Richard Amelius, Messrs. John Spencer and Sons, Tyne Hæmatite Iron Works, Scotswood-on-Tyne.

1860. Lewis, Thomas William, Tydfil House, Merthyr Tydfil.
1884. Lewis, William Thomas, Bute Mineral Estate Office, Aberdare; and Mardy, Aberdare.
1880. Lightfoot, Thomas Bell, Cornwall Buildings, 35 Queen Victoria Street, London, E.C.
1856. Linn, Alexander Grainger, 121 Upper Parliament Street, Liverpool.
1876. Lishman, Thomas, Mining Engineer, Hetton Colliery, near Fence Houses.
1881. List, John, Superintendent Engineer, Messrs. Donald Currie and Co., Orchard Works, Blackwall, London, E.
1866. Little, George, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.
1867. Livesey, James, 2 Victoria Mansions, Victoria Street, Westminster, S.W.
1867. Lloyd, Charles, 69 Millbank Street, Westminster, S.W.
1871. Lloyd, Francis Henry, James Bridge Steel Works, near Wednesbury; and Wood Green, Wednesbury.
1854. Lloyd, George Braithwaite, Edgbaston Grove, Birmingham. (*Life Member.*)
1882. Lloyd, Robert Samuel, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.
1864. Lloyd, Sampson Zachary, Areley Hall, Stourport.
1852. Lloyd, Samuel, The Farm, Sparkbrook, Birmingham.
1879. Lockhart, William Stronach, Fenchurch House, 7 Fenchurch Street, London, E.C.
1881. Lockyer, Norman Joseph, Manchester Sheffield and Lincolnshire Railway, Locomotive Department, Gorton, Manchester.
1884. Logan, Andrew Linton, Lochalsh, Scotland.
1883. Logan, Robert Patrick Tredennick, Engineer's Office, Great Northern Railway of Ireland, Dundalk.
1874. Logan, William, Mining Engineer, Langley Park Colliery, Durham.
1884. Longbottom, Luke, Locomotive Superintendent, North Staffordshire Railway, Stoke-on-Trent.
1880. Longridge, Michael, Chief Engineer, Engine and Boiler Insurance Co., 12 King Street, Manchester.
1856. Longridge, Robert Bewick, Managing Director, Engine and Boiler Insurance Co., 12 King Street, Manchester; and Yew Tree House, Tabley, near Knutsford.
1875. Longridge, Robert Charles, Kilrie, Knutsford.
1880. Longworth, Daniel, Carnac Iron Works, Bombay.
1882. Lord, Walter, Messrs. Lord Brothers, Canal Street Works, Todmorden.
1861. Low, George, Bishop's Hill Cottage, Ipswich.
1884. Lowcock, Arthur, Coleham Foundry, Shrewsbury.
1884. Lowdon, John, Manager, Tyneside Engine Works, Cardiff.

1873. Lowe, John Edgar, Messrs. Bolling and Lowe, 2 Laurence Pountney Hill, London, E.C.

1883. Lowe, Sutton Harvey, Eastgate House, Lincoln.

1873. Lucas, Arthur, 15 George Street, Hanover Square, London, W.

1877. Lupton, Arnold, 4 Albion Place, Leeds.

1878. Lüthy, Robert, Messrs. Hick Hargreaves and Co., Soho Iron Works, Bolton.

1878. Lynde, James Henry, 32 St. Ann's Street, Manchester.

1883. Macbeth, Norman, Messrs. John and Edward Wood, Victoria Foundry, Bolton.

1884. MacCarthy, Samuel, Messrs. Hathorn Davey and Co., Sun Foundry, Leeds.

1877. MacColl, Hector, Messrs. James Jack and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.

1879. Macdonald, Augustus VanZundt, District Manager, New Zealand Railways, Napier, New Zealand.

1864. Macfarlane, Walter, Saracen Foundry, Possilpark, Glasgow.

1884. Mackintosh, Archibald Robert, Messrs. Campbell Mackintosh and Bowstead, Scotswood Ship Yard, Newcastle-on-Tyne.

1875. Maclagan, Robert, Chief Engineer, Imperial Mint, Osaka, Japan: (or care of Dr. Maclagan, 9 Cadogan Place, Belgrave Square, London, S.W.)

1877. MacLellan, John A., Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow.

1864. Macnab, Archibald Francis, Inspecting and Examining Engineer, Government Marine Office, Tokio, Japan.

1865. Macnee, Daniel, 2 Westminster Chambers, Victoria Street, Westminster, S.W.; and Rotherham.

1884. Macpherson, Alexander Sinclair, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1879. Maginnis, James Porter, 23 Queen Anne's Gate, Westminster, S.W.

1873. Mair, John George, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1879. Malcolm, Bowman, Locomotive Superintendent, Belfast and Northern Counties Railway, Belfast.

1881. Mallory, George Benjamin, 55 Broadway, New York.

1882. Mañé, Marcos, Ingeniero Mecanico, Ferro Carril Oeste, Buenos Aires.

1876. Manlove, William Melland, Messrs. S. Manlove and Sons, Holy Moor Sewing-Cotton Spinning Mills, near Chesterfield.

1862. Mansell, Richard Christopher, Mechanical Engineer, South Eastern Railway; 24 Caversham Road, Kentish Town, London, N.W.

1875. Mansergh, James, 3 Westminster Chambers, Victoria Street, Westminster, S.W.

1862. Mappin, Frederick Thorpe, M.P., Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield; and Thornbury, Sheffield.
1882. Mappin, Walter Sandell, 13 Cornhill, London, E.C.
1857. March, George, Messrs. Maclea and March, Union Foundry, Dewsbury Road, Leeds.
1878. Marié, George, Engineer, Chemins de fer de Paris à Lyon et à la Méditerranée, Bureaux du Matériel, Boulevart Mazas, Paris.
1856. Markham, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield; and Tapton House, Chesterfield.
1884. Marquand, Augustus John, 109 Rothesay Terrace, Bute Docks, Cardiff.
1871. Marsh, Henry William, Winterbourne, near Bristol.
1875. Marshall, Alfred, Perseverance Iron Works, Heneage Street, Whitechapel, London, E.; and Laurel Bank, Prospect Hill, Walthamstow, Essex. (*Life Member.*)
1865. Marshall, Francis Carr, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.
1871. Marshall, James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.
1877. Marshall, William Bayley, 15 Augustus Road, Birmingham.
1847. Marshall, William Prime, 15 Augustus Road, Birmingham.
1859. Marten, Edward Bindon, Chief Engineer, Midland Steam Boiler Inspection and Assurance Company, 56 Hagley Street, Stourbridge; and Pedmore, Stourbridge.
1853. Marten, Henry John, The Birches, Codsall, near Wolverhampton; and 4 Storey's Gate, Westminster, S.W.
1881. Martin, Edward Pritchard, Dowlais Iron Works, Dowlais.
1878. Martin, Henry, Hanwell, Middlesex, W.
1880. Martin, Robert Frewen, Mount Sorrel Granite Co., Loughborough.
1854. Martineau, Francis Edgar, Globe Works, 278 New Town Row, Birmingham.
1882. Masefield, Robert, Manor Iron Works, Manor Street, Chelsea, London, S.W.
1884. Massey, George, Messrs. Haughton and Co., 110 Cannon Street, London, E.C.
1876. Mather, John, London and South Western Railway, Locomotive Department, Nine Elms, London, S.W.
1867. Mather, William, Messrs. Mather and Platt, Salford Iron Works, Manchester.
1883. Mather, William Penn, Messrs. Mather and Platt, Salford Iron Works Manchester.
1882. Matheson, Henry Cripps, care of Messrs. Russell and Co., Hong Kong, China: (or care of Messrs. Matheson and Grant, 32 Walbrook, London, E.C.)

1875. Matthews, James, 22 Ashfield Terrace East, Newcastle-on-Tyne.

1875. Mattos, Antonio Gomes de, Messrs. Maylor and Co., Engineering Works, 136 Rua da Sande, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1853. Maudslay, Henry, Westminster Palace Hotel, Victoria Street, Westminster, S.W.: (or care of John Barnard, 47 Lincoln's Inn Fields, London, W.C.) (*Life Member.*)

1869. Maughan, Thomas, Engineer, Cramlington Colliery, Cramlington, Northumberland.

1873. Maw, William Henry, 35 Bedford Street, Strand, London, W.C.

1884. Maxim, Hiram Stevens, 57D Hatton Garden, London, E.C.

1865. Maylor, John, Churton Lodge, Churton, near Chester.

1859. Maylor, William, Calicut, Malabar Coast, India: (or care of Messrs. Leslie and Anderson, 2 Lime Street Square, London, E.C.)

1874. McClean, Frank, 23 Great George Street, Westminster, S.W.

1872. McConnochie, John, Engineer to the Bute Harbour Trust, 16 Bute Crescent, Bute Docks, Cardiff.

1878. McDonald, John Alexander, Assistant Engineer for Roads and Bridges, Public Works Office, Sydney, New South Wales: (or care of James E. McDonald, 4 Chapel Street, Cripplegate, London, E.C.)

1865. McDonnell, Alexander, Locomotive Superintendent, North Eastern Railway, Gateshead; and Saltwell Hall, Gateshead.

1881. McGregor, Josiah, Crown Buildings, 78 Queen Victoria Street, London, E.C.

1868. McKay, Benjamin, Ice Works, Rockhampton, Queensland: (or care of Messrs. Lear Phillips and Co., 38 Dean Street, Birmingham.)

1881. McKay, John, Messrs. R. and W. Hawthorn, St. Peter's Works, Newcastle-on-Tyne.

1880. McLachlan, John, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley.

1882. McLaren, Raynes Lauder, Bourse Buildings, 20 Bucklersbury, London, E.C.; and 14 Royal Parade, Blackheath, London, S.E.

1879. McLean, William Leckie Ewing, Lancefield Forge Co., Glasgow.

1884. McOnie, William, Jun., Messrs. W. and A. McOnie, Scotland Street Engine Works, Glasgow.

1882. Meats, John Tempest, Mason Machine Works, Taunton, Massachusetts, United States.

1863. Meek, Sturges, Resident Engineer, Lancashire and Yorkshire Railway, Manchester.

1881. Meik, Charles Scott, 6 York Place, Edinburgh.

1858. Meik, Thomas, 6 York Place, Edinburgh.

1883. Melrose, James, Chief Engineer, H.M. Dockyard, Gibraltar.

1878. Menier, Henri, 37 Rue Ste. Croix de la Bretonnerie, Paris.

1876. Menzies, William, Messrs. Menzies and Blagburn, 9 Dean Street, Newcastle-on-Tyne.

1875. Merryweather, James Compton, Messrs. Merryweather and Sons, Fire-Engine Works, Greenwich Road, London, S.E.; and 63 Long Acre, London, W.C.

1881. Meysey-Thompson, Arthur Herbert, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds.

1877. Michele, Vitale Domenico de, 14 Delahay Street, Westminster, S.W.; and Higham Hall, Rochester.

1884. Middleton, Reginald Empson, Forth Bridge, South Queensferry, Scotland.

1862. Miers, Francis C., Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.; and Eden Cottage, West Wickham Road, Beckenham.

1864. Miers, John William, 74 Addison Road, Kensington, London, W.

1874. Milburn, John, Hawkshead Foundry, Quay Side, Workington.

1856. Mitchell, Charles, Sir W. G. Armstrong Mitchell and Co., Low Walker, Newcastle-on-Tyne; and Jesmond Towers, Newcastle-on-Tyne.

1870. Moberly, Charles Henry, Messrs. Easton and Anderson, Erith Iron Works, Erith, London, S.E.

1879. Moffat, Thomas, Mining Engineer, Montreal Iron Ore Mines, Whitehaven.

1879. Molesworth, Guilford Lindsay, Consulting Engineer to the Government of India for State Railways, Supreme Government, India.

1882. Molesworth, James Murray, Chinese Engineering and Mining Co., care of H. B. M. Consulate, Tientsin, China; and Spotland Vicarage, Rochdale: (or care of Messrs. Price and Belsham, 52 Queen Victoria Street, London, E.C.)

1881. Molinos, Léon, 48 Rue de Provence, Paris.

1884. Monroe, Robert, Manager, Penarth Slipway and Engineering Works, Penarth Dock, Penarth.

1872. Moon, Richard, Jun., Penyvoel, Llanymynech, Montgomeryshire.

1884. Moore, Benjamin Theophilus, Cavendish House, Teddington, Middlesex.

1876. Moore, Joseph, Risdon Iron and Locomotive Works, San Francisco, California: (or care of Ralph Moore, Government Inspector of Mines, Rutherglen, Glasgow.)

1882. Moore, Richard St. George, Messrs. Clarke and Moore, 7 Westminster Chambers, Victoria Street, Westminster, S.W.

1872. Moorsom, Warren Maude, Linden Lodge, Clevedon.

1880. Moreland, Richard, Jun., Messrs. Richard Moreland and Son, 3 Old Street, St. Luke's, London, E.C.

1867. Morgans, Thomas, The Guildhall, Bristol.

1874. Morris, Edmund Legh, New River Water Works, Finsbury Park, London, N.

1865. Mosse, James Robert, General Director of Ceylon Railways; 4 Eaton Gardens, Ealing, London, W.

1858. Mountain, Charles George, Rose Hill House, Coalbrookdale, Shropshire.

1884. Mower, George A., Crosby Steam Gage and Valve Co., 21 Cross Street, Finsbury, London, E.C.

1873. Muir, Alfred, Messrs. William Muir and Co., Britannia Works, Sherborne Street, Strangeways, Manchester.

1873. Muir, Edwin, 26 King Street, Manchester.

1863. Muir, William, 2 Walbrook, London, E.C.; and 143 Brockley Road, New Cross, London, S.E.

1876. Muirhead, Richard, Messrs. Drake and Muirhead, Maidstone.

1865. Murdock, William Mallabey, Gilwern, near Abergavenny.

1881. Musgrave, James, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton.

1863. Musgrave, John, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton.

1882. Musgrave, Walter Martin, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton.

1870. Napier, James Murdoch, Messrs. David Napier and Son, Vine Street, York Road, Lambeth, London, S.E.

1861. Naylor, John William, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1883. Neate, Percy John, Messrs. Taylor and Neate, Medway Works, Rochester.

1863. Neilson, Walter Montgomerie, Hyde Park Locomotive Works, Glasgow; and Queen's Hill, Ringford, Kirkcudbrightshire.

1884. Nelson, John, St. Martin's House, Micklegate, York.

1881. Nesfield, Arthur, 7 Rumford Street, Liverpool.

1882. Nettlefold, Hugh, Screw Works, Broad Street, Birmingham.

1879. Neville, Robert, Butleigh Court, Glastonbury.

1879. Newall, Robert Stirling, F.R.S., Wire Rope Works, Gateshead; and Ferndene, Gateshead.

1866. Newdigate, Albert Lewis, 25 Craven Street, Charing Cross, London, W.C. (*Life Member.*)

1881. Newman, Frederick, 5 Copthall Buildings, London, E.C.

1881. Nichol, Bryce Gray, Messrs. Donkin and Nichol, St. Andrew's Iron Works, Newcastle-on-Tyne.

1882. Nicholl, Edward McKillop, Bengal Public Works Department, Amritsar, Punjaub, India: (or care of Messrs. Henry S. King and Co., 65 Cornhill, London, E.C.)

1884. Nicholls, James Mayne, Locomotive Superintendent, Nitrate Railways, Iquique, Chile.

1884. Nicholson, Henry, 21 Flaxman Street, Liverpool.

1884. Nicholson, Thomas Head, Bedouin Steam Navigation Co., Liverpool; and 32 Rye Hill, Newcastle-on-Tyne.

1884. Nicholson, Walter Elliott, Tyne Boiler Works, Low Walker Newcastle-on-Tyne.

1877. Nicolson, Donald, 42 Highbury Hill, London, N.

1884. Noakes, Walter Maplesden, 43 York Street, Wynyard Square, Sydney, New South Wales.

1882. Nordenfelt, Thorsten, 53 Parliament Street, Westminster, S.W.

1866. Norfolk, Richard, Beverley.

1868. Norris, William Gregory, Coalbrookdale Iron Works, Coalbrookdale, Shropshire.

1869. North, Frederic William, Mining Engineer, Rowley Hall, near Dudley.

1883. North, Gamble, Messrs. North and Jewel, Peruano Nitrate of Soda and Iodine Works, Iquique, Chile: (or care of John T. North, Avery House, Avery Hill, Eltham.)

1882. North, John Thomas, Messrs. North Humphrey and Dickenson, Engineering Works, Iquique, Chile; and Avery House, Avery Hill, Eltham.

1878. Northcott, William Henry, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E.; and 7 St. Mary's Road, Peckham, London, S.E.

1882. Nunneley, Thomas, Messrs. Dawson and Nunneley, Black Bull Street, Hunslet, Leeds.

1868. O'Connor, Charles, Mersey Forge, Liverpool.

1875. Okes, John Charles Raymond, 39 Queen Victoria Street, London, E.C.

1880. Oldham, Robert Augustus, 17 Clarendon Road, Kensington, London, W.

1866. Oliver, William, Victoria and Broad Oaks Iron Works, Chesterfield.

1882. Olrick, Harry, 27 Leadenhall Street, London, E.C.

1882. Orange, James, Surveyor General's Department, Hong Kong, China.

1870. Osborn, Samuel, Clyde Steel and Iron Works, Sheffield.

1867. Oughterson, George Blake, care of Peter Brotherhood, Belvedere Road, Lambeth, London, S.E.

1868. Paget, Arthur, Machine Works, Loughborough.

1881. Palmer, Cecil Brooke, Minnie Moor Mining Co., Bellevue, Idaho, United States.

1877. Panton, William Henry, General Manager, Stockton Forge, Stockton-on-Tees.

1877. Park, John Carter, Locomotive Engineer, North London Railway, Bow, London, E.

1871. Parke, Frederick, Withnell Fire Clay Works, near Chorley.

1872. Parker, Thomas, Carriage Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.

1879. Parker, William, Chief Engineer Surveyor, Lloyd's Register, 2 White Lion Court, Cornhill, London, E.C.

1871. Parkes, Pershouse, 25 Exchange Buildings, Birmingham.

1884. Parlane, William, Hong Kong Ice Works, Eastpoint, Hong Kong, China.

1881. Parry, Henry, 2 Side, Newcastle-on-Tyne.

1880. Parsons, The Hon. Charles Algernon, Lauder Grange, Corbridge-on-Tyne.

1878. Parsons, The Hon. Richard Clere, Messrs. Kitson and Co., Airedale Foundry, Leeds.

1877. Paton, John McClure Caldwell, Messrs. Manlove Alliott Fryer and Co., Bloomsgrove Works, Ilkeston Road, Nottingham.

1881. Patterson, Anthony, Dowlais Iron Works, Dowlais.

1881. Pattinson, John, Locomotive Superintendent, Riazan and Kosloff Railway, Kosloff, Russia: (or care of Nathaniel Grew, Dashwood House, 9 New Broad Street, London, E.C.)

1883. Pattison, Giovanni, Messrs. C. and T. T. Pattison, Engineering Works, Naples.

1884. Paul, Andrew Louis, Engineer, Oriental Telephone Co., India; 38 Ashburn Place, London, S.W.

1872. Paxman, James Noah, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester.

1880. Peache, James Courthope, The Firs, Hampstead Heath, London, N.W.

1869. Peacock, Ralph, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1869. Peacock, Ralph, Aire and Calder Foundry, Goole.

1847. Peacock, Richard, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and Gorton Hall, Gorton, near Manchester.

1874. Peaker, George, Engineer to the Small Arms Ammunition Factory, Kirkee, India.

1879. Pearce, George Cope, 2 St. Helen's Crescent, Swansea.

1873. Pearce, Richard, Deputy Carriage and Wagon Superintendent, East Indian Railway, Howrah, Bengal, India: (or care of W. J. Titley, 57 Lincoln's Inn Fields, London, W.C.)

1867. Pearce, Robert Webb, Carriage Superintendent, East Indian Railway, Howrah, Bengal, India; and 47 Gunterstone Road, West Kensington, London, W.

1884. Pearson, Frank Henry, Earle's Shipbuilding and Engineering Works, Hull.

1870. Pearson, Thomas Henry, Moss Side Iron Works, Ince, near Wigan.
1884. Penn, George Williams, Lloyd's Bute Proving House, Cardiff.
1873. Penn, John, Messrs. John Penn and Sons, Marine Engineers, Greenwich, S.E.
1873. Penn, William, Messrs. John Penn and Sons, Marine Engineers, Greenwich, S.E.
1874. Percy, Cornelius McLeod, King Street, Wigan.
1861. Perkins, Loftus, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.
1879. Perkins, Stanhope, Assistant Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, Manchester.
1882. Perry, Alfred, Lighthouse Department, Messrs. Chance Brothers and Co., Spon Lane, near Birmingham.
1863. Perry, Thomas J., Highfields Engine Works, Bilston.
1865. Perry, William, Claremont Place, Wednesbury.
1882. Petherick, Vernon, Post Office, Brisbane, Queensland: (or care of Messrs. Manlove Alliott Fryer and Co., Ilkeston Road, Nottingham.)
1881. Philipson, John, Messrs. Atkinson and Philipson, Carriage Manufactory, 15 Pilgrim Street, Newcastle-on-Tyne.
1878. Phillips, John, Manager, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.; and 84 Blackfriars Road, London, S.E.
1879. Phillips, Robert Edward, Royal Courts Chambers, 70 and 72 Chancery Lane, London, W.C.; and Rochelle, Selhurst Road, South Norwood, London, S.E.
1882. Phipps, Christopher Edward, Deputy Locomotive Superintendent, Madras Railway, Perambore Works, Madras: (or care of Rev. E. J. Phipps, Stansfield Rectory, Clare, Suffolk.)
1876. Piercy, Henry James Taylor, Messrs. Piercy and Co., Broad Street Engine Works, Birmingham.
1877. Pigot, Thomas Francis, Professor of Engineering, Royal College of Science for Ireland, Dublin.
1883. Pillow, Edward, London and North Western Railway, Locomotive Department, Crewe.
1876. Pinel, Charles Louis, Messrs. Lethuillier and Pinel, 26 Rue Meridienne, Rouen, France.
1882. Pirrie, John Sinclair, Messrs. Fraser and Miller, Carnac Iron Works, Bombay: (or care of Messrs. Ironside Gyles and Co., 5 Barge Yard, Bucklersbury, London, E.C.)
1883. Pitt, Walter, Messrs. Stothert and Pitt, Newark Foundry, Bath.
1871. Platt, James, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester.

1883. Platt, James Edward, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. Platt, Samuel Radcliffe, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1878. Platts, John Joseph, Resident Engineer, Odessa Water Works, Odessa, Russia ; and 27 Fernbank Road, Redland, Bristol.

1869. Player, John, Clydach Foundry, near Swansea.

1884. Poillon, Louis Marie Joseph, 74 Boulevard Mont-Parnasse, Paris.

1876. Pollock, Julius Frederick Moore, Messrs. Pollock and Pollock, Longclose Works, Newtown, Leeds.

1876. Pooley, Henry, Messrs. Henry Pooley and Son, Albion Foundry, Liverpool.

1869. Potter, William Aubone, Mining Engineer, Cramlington House, Cramlington, Northumberland.

1864. Potts, Benjamin Langford Foster, 55 Chancery Lane, London, W.C. ; and 5 Camden Row, Camberwell, London, S.E.

1851. Potts, John Thorpe, Messrs. Richmond and Potts, 119 South Fourth Street, Philadelphia, Pennsylvania, United States.

1878. Powell, Henry Coke, care of Thomas Powell, 23 Rue St. Julien, Rouen, France: (or care of C. M. Roffe, 1 Bedford Row, London, W.C.)

1870. Powell, Thomas (Son), Messrs. Thomas and T. Powell, 23 Rue St. Julien, Rouen, France.

1874. Powell, Thomas (Nephew), Brynhyfryd, Neath.

1867. Pratchitt, John, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1865. Pratchitt, William, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1882. Presser, Ernest Charles Antoine, 4 Salesas, Madrid.

1884. Prest, Stanley Faber, Messrs. Westray Copeland and Co., Barrow-in-Furness.

1856. Preston, Francis, Netherfield House, Kirkburton, near Huddersfield.

1877. Price, Henry Sherley, Messrs. Wheatley Kirk, Price, and Goulty, 52 Queen Victoria Street, London, E.C.

1866. Price, John, General Manager, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow ; and Rose Villa, Gateshead Road, Jarrow.

1859. Price-Williams, Richard, 38 Parliament Street, Westminster, S.W.

1875. Prior, Johannes Andreas, 33 Bredgade, Copenhagen.

1874. Prosser, William Henry, Messrs. Harfield and Co., Mansion House Buildings, Queen Victoria Street, London, E.C.

1875. Provis, George Stanton, Ingoldsby, Belvedere Road, Upper Norwood, London, S.E.

1884. Puplett, Samuel, Messrs. Thomas Piggott and Co., Atlas Engine Works, Oozells Street, Birmingham.

1866. Putnam, William, Darlington Forge, Darlington.

1878. Quillacq, Augustus de, Société anonyme de Constructions mécaniques d'Anzin, Anzin (Nord), France.

1873. Radcliffe, Arthur Henry Wright, 5 Carr's Lane, Birmingham.
1870. Radcliffe, William, Camden House, 25 Collegiate Crescent, Sheffield.
1878. Radford, Richard Heber, 15 St. James' Row, Sheffield.
1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.
1884. Rafarel, William Claude, Barnstaple Foundry and Engineering Works, Victoria Road, Barnstaple.
1878. Rait, Henry Milnes, Messrs. Rait and Lindsay, Cranstonhill Foundry, Glasgow; and 155 Fenchurch Street, London, E.C.
1847. Ramsbottom, John, Fernhill, Alderley Edge, Cheshire.
1866. Ramsden, Sir James, Abbot's Wood, Barrow-in-Furness.
1860. Ransome, Allen, 304 King's Road, Chelsea, London, S.W.
1869. Ransome, Robert Charles, Messrs. Ransomes Head and Jefferies, Orwell Works, Ipswich.
1862. Ransome, Robert James, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich.
1873. Rapier, Richard Christopher, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich; and 5 Westminster Chambers, Victoria Street, Westminster, S.W.
1883. Rathbone, Edgar Philip, Mining Engineer, 2 Great George Street, Westminster, S.W.
1867. Ratliffe, George, care of G. H. Horsfall, 17 James Street, Liverpool.
1862. Ravenhill, John R., 27 Courtfield Gardens, South Kensington, London, S.W.
1872. Rawlins, John, Manager, Metropolitan Railway-Carriage and Wagon Works, Saltley, Birmingham.
1878. Rawlinson, Sir Robert, C.B., Chief Inspector, Local Government Board, Whitehall, London, S.W.
1883. Reader, Reuben, Phœnix Works, Cremorne Street, Nottingham.
1882. Reay, Thomas Purvis, Messrs. Kitson and Co., Airedale Foundry, Leeds.
1881. Redpath, Francis Robert, Canada Sugar Refinery, Montreal, Canada.
1883. Reed, Alexander Henry, 90 Cannon Street, London, E.C.
1881. Reed, Charles Holloway, Trimdon Iron Works, Sunderland.
1870. Reed, Sir Edward James, K.C.B., M.P., F.R.S., Broadway Chambers, Westminster, S.W.
1884. Rees, William David, Swansea Railway-Carriage and Wagon Works, Swansea.
1884. Rees, William Thomas, Mining Engineer, Gadlys Cottage, Aberdare.

1883. Reid, James, Messrs. Neilson and Co., Hyde Park Locomotive Works, Glasgow.

1859. Rennie, George Banks, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.; and 20 Lowndes Street, Lowndes Square, London, S.W.

1878. Rennie, John, care of H. T. Lannigan, 9 Laurence Pountney Lane, Cannon Street, London, E.C.

1879. Rennie, John Keith, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.

1881. Rennoldson, Joseph Middleton, Marine Engine Works, South Shields.

1876. Restler, James William, Engineer, Southwark and Vauxhall Water Works, Sumner Street, Southwark, London, S.E.

1883. Reunert, Theodore, Kimberley, South Africa; and Benson's Buildings, Park Row, Leeds.

1862. Reynolds, Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1879. Reynolds, George Bernard, Assistant Manager, Warda Coal State Railway, Warora, Central Provinces, India: (or care of Messrs. Stilwell, 22 Arundel Street, Strand, London, W.C.)

1882. Rhodes, Vincent, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.

1875. Rich, William Edmund, Engineer, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.

1866. Richards, Edward Windsor, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough.

1882. Richards, George, Messrs. George Richards and Co., Atlantic Works, Broadheath, near Manchester.

1856. Richards, Josiah, Pontypool Iron and Tinplate Works, Pontypool.

1884. Richards, Lewis, Dowlais Iron and Steel Works, Dowlais.

1863. Richardson, The Hon. Edward, C.M.G., Minister of Public Works, Christchurch, Canterbury, New Zealand.

1881. Richardson, George, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1865. Richardson, John, Methley Park, near Leeds.

1873. Richardson, John, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1859. Richardson, William, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1884. Riches, Charles Hurry, Assistant Locomotive Superintendent, Taff Vale Railway, Cardiff.

1874. Riches, Tom Hurry, Locomotive Superintendent, Taff Vale Railway, Cardiff.

1873. Rickaby, Alfred Austin, Bloomfield Engine Works, Sunderland.

1879. Ridley, James Cartmell, Queen Street, Newcastle-on-Tyne.

1863. Rigby, Samuel, Fern Bank, Liverpool Road, Chester.
1874. Riley, James, General Manager, Steel Company of Scotland, 150 Hope Street, Glasgow.
1879. Rixom, Alfred John, Woodstone Steam Brick and Tile Works, Peterborough; and 38 The Grove, Hammersmith, London, W.
1879. Roberts, Thomas Herbert, Mechanical Superintendent, Chicago and Grand Trunk Railway, Fort Gratiot, Michigan, United States.
1848. Robertson, Henry, M.P., Great Western Railway, Shrewsbury; and 13 Lancaster Gate, London, W.; and Palé, Corwen.
1879. Robertson, William, Messrs. Boyd and Co., Engineers and Shipbuilders, Shanghai, China: (or care of Andrew Bruce, 46 Queen Victoria Street, London, E.C.)
1883. Robins, Edward, Assistant Engineer, Public Works Department, Suddie Essequibo, British Guiana: (or care of Charles Robins, 21 Granville Road, Cambrian View, Chester).
1874. Robinson, Henry, 7 Westminster Chambers, Victoria Street, Westminster, S.W.
1876. Robinson, James Salkeld, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.
1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester; and Westwood Hall, Leek, near Stoke-upon-Trent.
1878. Robinson, John Frederick, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1878. Robinson, Thomas Neild, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.
1866. Robson, Thomas, Mining Engineer, Lumley Thicks, Fence Houses.
1879. Rodger, William, care of Messrs. Ralli Brothers, Bombay.
1884. Rodrigues, José Maria de Chermont, Société de St. Léonard, Liége, Belgium.
1872. Rofe, Henry, Cavendish Hill, Sherwood, Nottingham.
1868. Rogers, William, Sergipe, care of Messrs. Hugh Wilson and Son, Bahia, Brazil: (or care of J. Kenyon Rogers, 25 Water Street, Liverpool.)
1871. Rollo, David, Messrs. David Rollo and Sons, Fulton Engine Works, 10 Fulton Street, Liverpool.
1867. Rose, Thomas, 14 Bank Street, Cross Street, Manchester.
1874. Ross, John Alexander George, 46 Grainger Street West, Newcastle-on-Tyne.
1881. Ross, William, Messrs. Ross and Walpole, North Wall Iron Works, Dublin.
1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Peterborough.
1878. Routh, William Pole, 25 Rua de S. Francisco, Oporto, Portugal: (or care of Cyril E. Routh, St. Michael's House, Cornhill, London, E.C.)

1880. Routledge, Thomas, Ford Paper Works, Sunderland; and Claxheugh, Sunderland.

1878. Russell, The Hon. William, George Town, Demerara, British Guiana; and 65 Holland Park, London, W.

1867. Ruston, Joseph, M.P., Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln; and 6 Onslow Gardens, South Kensington, London, S.W.

1884. Rutherford, George, Manager, Wallsend Slipway and Engineering Works, Cardiff.

1877. Rutter, Edward, Messrs. Seaward and Co., Canal Iron Works, Millwall, London, E.

1883. Ryder, George, Turner Bridge Iron Works, Tong, near Bolton.

1866. Ryland, Frederick, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich.

1866. Sacré, Alfred Louis, 60 Queen Victoria Street, London, E.C.

1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Manchester.

1883. Sadoine, Eugène, Société Cockerill, Seraing, Belgium.

1864. Said, Colonel M., Pasha, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 22 Great George Street, Westminster, S.W.)

1859. Salt, George, Sir Titus Salt, Bart., Sons and Co., Saltaire, near Bradford; and Royal Thames Yacht Club, 7 Albemarle Street, London, W.

1874. Sampson, James Lyons, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N.

1864. Samuda, Joseph D'Aguilar, Iron Ship Building Yard, Isle of Dogs, Poplar, London, E.

1865. Samuelson, Sir Bernhard, Bart., M.P., F.R.S., Britannia Iron Works, Banbury; and 56 Prince's Gate, South Kensington, London, S.W.; and Lupton, Brixham, South Devon.

1881. Samuelson, Ernest, Messrs. Samuelson and Co., Britannia Iron Works, Banbury.

1881. Sanders, Henry Conrad, Messrs. H. G. Sanders and Son, Victoria Works, Victoria Gardens, Notting Hill Gate, London, W.; and 7 Boscombe Road, Shepherd's Bush, London, W.

1871. Sanders, Richard David, Norwood, Lenzie, Dumbartonshire.

1881. Sandiford, Charles, Locomotive Superintendent, Scinde Punjaub and Delhi Railway, Lahore, Punjaub, India.

1874. Sauvée, Albert, 22 Parliament Street, Westminster, S.W.

1882. Sawyer, Frederic Henry Read, 18 Calle Real de San Miguel, Manila, Philippine Islands; and 4 Cullum Street, London, E.C.

1880. Saxby, John, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W.

1869. Scarlett, James, Messrs. E. Green and Son, 14 St. Ann's Square, Manchester.

1883. Schönheyder, William, 81 St. Stephen's Avenue, Shepherd's Bush, London, W.

1880. Schram, Richard, 9 Northumberland Street, Strand, London, W.C.

1876. Scott, David, Port Commissioners' Office, Calcutta.

1875. Scott, Frederick Whitaker, Atlas Steel and Iron Wire Rope Works, Reddish, Stockport.

1881. Scott, George Innes, 4 Queen Street, Newcastle-on-Tyne.

1877. Scott, Irving M., Messrs. Prescott Scott and Co., Union Iron Works, San Francisco, California.

1881. Scott, James, Despatch Wool-Washing Co., Port Elizabeth, Algoa Bay, Cape Colony: (or care of Mr. Wallace, The Home Farm, Murthly, Perthshire.)

1884. Scott, John, Messrs. Charles Hill and Sons, Bristol.

1861. Scott, Walter Henry, Park Road, East Molesey, Kingston-on-Thames.

1884. Scott-Moncrieff, William Dundas, 4D Upper Baker Street, London, N.W.

1868. Scriven, Charles, Messrs. Scriven and Co., Leeds Old Foundry, Marsh Lane, Leeds; and Whinfield Mount, Chapel Allerton, Leeds.

1882. Seabrooke, Alfred William, Engineer Surveyor to the Port of Bombay, Port Office, Bombay.

1882. Seaton, Albert Edward, Earle's Shipbuilding and Engineering Works, Hull.

1864. Seddon, John, 98 Wallgate, Wigan.

1857. Selby, George Thomas, Woolton Hill, Newbury.

1882. Selfe, Norman, 141 Pitt Street, Sydney, New South Wales.

1884. Sellers, Coleman, Messrs. William Sellers and Co., 1600 Hamilton Street, Philadelphia; and 3301 Baring Street, Philadelphia, Pennsylvania, United States.

1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania, United States.

1881. Sennett, Richard, Admiralty, Whitehall, London, S.W.

1883. Shackleford, Arthur Lewis, General Manager, Britannia Railway-Carriage and Wagon Works, Saltley, Birmingham.

1884. Shackleford, William Copley, Manager, Lancaster Wagon Works, Lancaster.

1872. Shanks, Arthur, Messrs. A. Burn and Co., Howrah Iron Works, Howrah; and 7 Hastings Street, Calcutta.

1884. Shanks, William, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow.

1881. Shanks, William Weallens, 18 Strand Road, Howrah, Bengal.

1881. Shapton, William, Sir William G. Armstrong Mitchell and Co., 8 Great George Street, Westminster, S.W.

1863. Sharp, Henry, Bolton Iron and Steel Works, Bolton.

1875. Sharp, Thomas Budworth, Managing Engineer, Muntz Metal Works, Birmingham.

1867. Sharpe, Charles James, 27 Great George Street, Westminster, S.W.

1869. Sharrock, Samuel, Windsor Iron Works, Garston, near Liverpool; and 8 Old Jewry, London, E.C.

1882. Sharrock, Samuel Lord, Hydraulic Engineering Works, Chester.

1864. Shaw, Duncan, Mining Engineer, Cordoba, Spain.

1879. Shaw, Henry Selby Hele, Professor of Engineering, University College, Bristol.

1881. Shaw, Joshua, Messrs. John Shaw and Sons, Wellington Street Works, Salford, Manchester.

1881. Shaw, William, Jun., Stanners Closes Steel Works, Wolsingham, near Darlington.

1856. Shelley, Charles Percy Bysshe, 45 Parliament Street, Westminster, S.W.

1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.

1875. Sheppard, Herbert Gurney, East Indian Railway, Cawnpore, India; and 89 Westbourne Terrace, Hyde Park, London, W.

1876. Shield, Henry, Messrs. Fawcett Preston and Co., Phœnix Foundry 17 York Street, Liverpool.

1872. Shoolbred, James Nelson, 3 Westminster Chambers, Victoria Street, Westminster, S.W.

1871. Simon, Henry, 20 Mount Street, Manchester.

1877. Simonds, William Turner, Messrs. J. C. Simonds and Son, Oil Mills, Boston. (*Life Member.*)

1873. Simpson, Alfred, 11 High Street, Hull; and Denmark House, Alexandra Road, St. John's Wood, near Hull.

1876. Simpson, Arthur Telford, Engineer, Chelsea Water Works, 38 Parliament Street, Westminster, S.W.

1878. Simpson, James, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1882. Simpson, John Harwood, Severn Tunnel Works, Portskewett, near Chepstow.

1847. Sinclair, Robert, care of Messrs. Sinclair Hamilton and Co., 17 St. Helen's Place, Bishopsgate Street, London, E.C.

1857. Sinclair, Robert Cooper, 3 Adelaide Place, London Bridge, London, E.C.

1881. Sisson, William, Messrs. Cox and Co., Falmouth Docks Engine and Shipbuilding Works, Falmouth.

1872. Slater, Alfred, Gloucester Wagon Works, Gloucester.

1859. Slater, Isaac, Gloucester Wagon Works, Gloucester.

1853. Slaughter, Edward, 25 Caledonia Place, Clifton, Bristol.

1879. Smith, Allison Dalrymple, Locomotive Superintendent, Canterbury Railways, Christchurch, New Zealand.

1879. Smith, Charles Hubert, Engineer and Shipwright Surveyor to the Board of Trade, North Shields.

1866. Smith, Edward Fisher, The Priory Offices, Dudley.

1866. Smith, George Fereday, Grovehurst, Tunbridge Wells.

1860. Smith, Henry, Messrs. Hill and Smith, Brierley Hill Iron Works, Brierley Hill.

1881. Smith, Henry, Messrs. Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.

1860. Smith, John, Brass Foundry, Traffic Street, Derby.

1876. Smith, John, Wintoun Terrace, Rochdale.

1883. Smith, John Bagnold, Assistant Manager, Sheepbridge Coal and Iron Works, Chesterfield.

1857. Smith, Josiah Timmis, Hæmatite Iron and Steel Works, Barrow-in-Furness.

1870. Smith, Michael Holroyd, Royal Insurance Buildings, Crossley Street, Halifax.

1881. Smith, Robert Henry, Professor of Engineering, Mason Science College, Birmingham; and 10 St. Augustine's Road, Edgbaston, Birmingham.

1882. Smith, Walter Parker, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1881. Smith, Wasteneys, 59 Sandhill, Newcastle-on-Tyne.

1863. Smith, William Ford, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester.

1882. Smyth, James Josiah, Messrs. James Smyth and Sons, Peasenhall, Suffolk.

1884. Smyth, William Stopford, Engineer, Alexandra Docks, Newport, Monmouthshire.

1883. Snelus, George James, West Cumberland Iron and Steel Works, Workington.

1859. Sokoloff, Major-General Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt, Russia: (or care of Messrs. W. Collier and Co., Worsley Street, New Bailey Street, Salford, Manchester.)

1878. Sopwith, Thomas, Mining Engineer, 6 Great George Street, Westminster, S.W.

1884. Soulsby, James Charlton, Manager, Swansea Dry Docks and Engineering Works, 64 Mansel Terrace, Swansea.

1877. Soyres, Francis Johnstone de, Messrs. Bush and De Soyres, Bristol Iron Foundry, Bristol.

1878. Spencer, Alfred G., Messrs. George Spencer and Co., 77 Cannon Street, London, E.C.

1866. Spencer, Eli, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham; and The Knoll, Fulshaw Park, Wilmslow, near Manchester.
1878. Spencer, George, Messrs. George Spencer and Co., 77 Cannon Street, London, E.C.
1877. Spencer, John, Vulcan Tube Works, Westbromwich.
1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne.
1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.
1876. Spice, Robert Paulson, 21 Parliament Street, Westminster, S.W.
1862. Stableford, William, Broadwell House, Oldbury, near Birmingham.
1869. Stabler, James, 13 Effra Road, Brixton, London, S.W.
1880. Stafford, George, 17 Russell Street, Nottingham.
1877. Stanger, George Hurst, Queen's Chambers, North Street, Wolverhampton.
1875. Stanger, William Harry, 23 Queen Anne's Gate, Westminster, S.W.
1884. Stanton, Frederic Barry, General Manager, Railway-Carriage Works, Oldbury, near Birmingham.
1866. Stephens, John Classon, Messrs. Stephens and Co., Vulcan Iron Works, Sir John Rogerson's Quay, Dublin.
1874. Stephens, Michael, Locomotive Superintendent, Cape Government Railways, Cape Town, Cape of Good Hope.
1868. Stephenson, George Robert, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1879. Stephenson, Joseph Gurdon Leycester, 6 Drapers' Gardens, Throgmorton Street, London, E.C.
1876. Sterne, Louis, Messrs. L. Sterne and Co., Crown Iron Works, Glasgow; and 10 Victoria Chambers, Victoria Street, Westminster, S.W.
1875. Stevens, Arthur James, Uskside Iron Works, Newport, Monmouthshire.
1878. Stevenson, George Wilson, 38 Parliament Street, Westminster, S.W.
1877. Stewart, Alexander, Manager, Messrs. Thwaites Brothers, Vulcan Iron Works, Thornton Road, Bradford.
1878. Stewart, Duncan, Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow.
1851. Stewart, John, Blackwall Iron Works, Poplar, London, E.
1880. Stirling, James, Locomotive Superintendent, South Eastern Railway, Ashford.
1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Railway, Doncaster.
1875. Stoker, Frederick William, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow.
1877. Stokes, Alfred Allen, The White House, Pauntley, Newent, Gloucestershire.
1877. Stothert, George Kelson, Steam Ship Works, Bristol.

1884. Stronge, Charles, Great Southern Railway, Locomotive Department, Buenos Aires; Post Office, Buenos Aires, Argentine Republic.

1865. Stroudley, William, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton; and Bosvigo, Preston Park, Brighton.

1873. Strype, William George, The Murrough, Wicklow.

1878. Stuart, James, M.P., Professor of Mechanism in Cambridge University, Trinity College, Cambridge.

1882. Sturgeon, John, 3 Westminster Chambers, Victoria Street, Westminster, S.W.

1882. Sugden, Thomas, Chadderton Iron Works, Irk Vale, Chadderton, near Manchester.

1861. Sumner, William, 2 Brazennose Street, Manchester.

1875. Sutcliffe, Frederic John Ramsbottom, Engineer, Low Moor Iron Works, near Bradford.

1883. Sutton, Joseph Walker, London and North Western Railway, Locomotive Department, Crewe.

1880. Sutton, Thomas, Carriage and Wagon Superintendent, Furness Railway, Barrow-in-Furness.

1882. Swaine, John, Steel Company of Scotland, Newton, near Glasgow.

1884. Swan, Joseph Wilson, 57 Holborn Viaduct, London, E.C.

1882. Swinburne, William, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne.

1864. Swindell, James Swindell Evers, 16 and 17 Exchange Buildings, Stephenson Place, Birmingham; and Clent House, Stourbridge.

1878. Taite, John Charles, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C.

1882. Tandy, John O'Brien, London and North Western Railway, Locomotive Department, Crewe.

1875. Tangye, George, Messrs. Tangye Brothers, Cornwall Works, Soho, near Birmingham.

1861. Tangye, James, Messrs. Tangye Brothers, Cornwall Works, Soho, near Birmingham; and Aviary Cottage, Illogan, near Redruth.

1879. Tartt, William, Maythorn, Blindley Heath, Godstone, near Red Hill.

1876. Taunton, Richard Hobbs, Messrs. Taunton and Hayward, Star Tube Works, Heneage Street, Birmingham.

1882. Tayler, Alexander James Wallis, 63 Victoria Road, Kilburn, London, N.W.

1874. Taylor, Arthur, Pontgibaud Lead Works, Puy de Dôme, France; and 6 Queen Street Place, Upper Thames Street, London, E.C.

1874. Taylor, Henry Enfield, Mining Engineer, 15 Newgate Street, Chester.

1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead.

1873. Taylor, John, Midland Foundry, Queen's Road, Nottingham.

1867. Taylor, Joseph, Corinthian Villa, Acock's Green, near Birmingham.

1875. Taylor, Joseph Samuel, Messrs. Taylor and Challen, Derwent Foundry, 99 Constitution Hill, Birmingham.

1874. Taylor, Percyvale, Messrs. Burthe and Taylor, 26 Rue de Caumartin, Paris.

1882. Taylor, Robert Henry, Clare Villa, Hale's Road, Cheltenham.

1882. Taylor, Thomas Albert Oakes, Messrs. Taylor Brothers and Co., Clarence Iron Works, Leeds.

1883. Taylor, William, Midland Foundry, Queen's Road, Nottingham.

1876. Taylor, William Henry Osborne, Salford Villa, 12 Elm Grove, Peckham Rye, London, S.E.

1864. Tennant, Charles, M.P., The Glen, Innerleithen, near Edinburgh. (*Life Member.*)

1882. Terry, Stephen Harding, Local Government Board, Whitehall, London, S.W.

1877. Thom, William, Messrs. W. and J. Yates, Canal Foundry, Blackburn.

1867. Thomas, Joseph Lee, 16 Holland Road, Kensington, London, W.

1864. Thomas, Thomas, 19 The Parade, Cardiff.

1874. Thomas, William Henry, 15 Parliament Street, Westminster, S.W.

1875. Thompson, John, Highfields Boiler Works, Ettingshall, near Wolverhampton.

1883. Thompson, Richard Charles, Messrs. Robert Thompson and Sons, Southwick Shipbuilding Yard, Sunderland.

1857. Thompson, Robert, Victoria Chambers, Wigan; and Standish, near Wigan.

1880. Thompson, Thomas William, Messrs. Thompson and Gough, South Mersey Ferries, Birkenhead.

1879. Thomson, David, Craighead, West Heath, Belvedere, Kent.

1875. Thomson, James McIntyre, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow.

1868. Thomson, John, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow.

1880. Thornbery, William Henry, Jun., Corporation Chambers, 121 Colmore Row, Birmingham.

1868. Thornewill, Robert, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1877. Thornton, Frederic William, Hydraulic Engineering Works, Chester.

1882. Thornton, Hawthorn Robert, 87 Wood Lane, Shepherd's Bush, London, W.

1876. Thornycroft, John Isaac, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.

1882. Thow, William, Locomotive Superintendent, South Australian Railways, Adelaide, South Australia: (or care of Joseph Meilbek, 7 Westminster Chambers, Victoria Street, Westminster, S.W.)

1884. Thwaites, Arthur Hirst, Vulcan Iron Works, Bradford.

1884. Timmis, Illius Augustus, 2 Great George Street, Westminster, S.W.

1875. Tomkins, William Steele, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.

1857. Tomlinson, Joseph, Jun., Resident Engineer and Locomotive Superintendent, Metropolitan Railway, Neasden, London, N.W.

1867. Tonks, Edmund, Brass Works, Moseley Street, Birmingham.

1883. Tower, Beauchamp, 19 Great George Street, Westminster, S.W.

1883. Trentham, William Henry, 33 Portland Road, Notting Hill, London, W.

1876. Trevithick, Richard Francis, The Cliff, Penzance.

1873. Trow, Joseph, Messrs. William Trow and Sons, Union Foundry, Wednesbury; and Victoria House, Holyhead Road, Wednesbury.

1883. Turnbull, Charles Henry, Mersey Dock Estate, Dock Yard, Liverpool.

1884. Turner, Albert Harrison, 18 Provost Road, Haverstock Hill, London, N.W.

1866. Turner, Frederick, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich.

1882. Turner, Thomas, New British Iron Works, Corngreaves, near Birmingham.

1876. Turney, John, Messrs. Turney Brothers, Trent Bridge Leather Works, Nottingham.

1872. Turton, Thomas, Liverpool Forge Company, Brunswick Dock, Liverpool.

1867. Tweddell, Ralph Hart, 14 Delahay Street, Westminster, S.W.

1882. Tweedy, John, Messrs. Wigham Richardson and Co., Newcastle-on-Tyne.

1856. Tyler, Sir Henry Whatley, K.C.B., M.P., Pymmes Park, Edmonton, Middlesex.

1877. Tylor, Joseph John, 11 Little Queen Street, Westminster, S.W.

1878. Tyson, Isaac Oliver, Ousegate Iron Works, Selby.

1875. Unsworth, Thomas, 79 Piccadilly, Manchester.

1878. Unwin, William Cawthorne, Professor of Engineering, City and Guilds of London Central Institution, Exhibition Road, London, S.W.; and 7 Palace Gate Mansions, Kensington, London, W.

1875. Urquhart, Thomas, Locomotive Superintendent, Grazi and Tsaritsin Railway, Borisoglebsk, Russia: (or care of Walter Ross, Hill Top, Blythe Hill, Catford, London, S.E.)

1880. Valon, William Andrew McIntosh, Engineer, Corporation Gas and Water Works, Ramsgate.

1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.

1865. Vickers, Albert, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1861. Vickers, Thomas Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1883. Waddell, James, Superintending Engineer, Netherlands India Steam Navigation Co., Soerabaya, Java; 13 Austin Friars, London, E.C.; and 9 Ashton Terrace, Hillhead, Glasgow.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.

1879. Wadia, Nowrosjee Nesserwanjee, Manager, Manockjee Petit Manufacturing Co., Tardeo, Bombay: (or care of Messrs. Hick Hargreaves and Co., Soho Iron Works, Bolton.)

1875. Wailes, John William, Patent Shaft Works, Wednesbury.

1884. Wailes, Thomas Waters, General Manager, Mountstuart Dry Dock and Engineering Works, Cardiff.

1881. Wake, Henry Hay, Engineer to the River Wear Commission, Sunderland.

1882. Wakefield, William, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Grand Canal Street, Dublin.

1873. Waldenström, Eric Hugo, Manager, Broughton Copper Works, Broughton Road, Manchester.

1867. Walker, Benjamin, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds.

1877. Walker, David, Superintendent of Engineering Workshops, King's College, Strand, London, W.C.

1875. Walker, George, 95 Leadenhall Street, London, E.C.

1875. Walker, John Scarisbrick, Messrs. J. S. Walker and Brother, Pagefield Iron Works, Wigan; and 12 Ash Street, Southport.

1884. Walker, Sydney Ferris, 195 Severn Road, Cardiff; and Black Boy Yard, Nottingham.

1876. Walker, Thomas Ferdinand, Ship's Log Manufacturer, 58 Oxford Street, Birmingham.

1878. Walker, William, Kaliemaas, Alleyne Park, West Dulwich, London, S.E.

1863. Walker, William Hugill, Messrs. Walker Eaton and Co., Wicker Iron Works, Sheffield.

1878. Walker, Zaccheus, Jun., Fox Hollies Hall, near Birmingham.

1884. Wallace, John, Backworth Collieries, near Newcastle-on-Tyne.

1884. Wallau, Frederick Peter, Messrs. Harland and Wolff, Belfast.

1868. Wallis, Herbert, Mechanical Superintendent, Grand Trunk Railway, Montreal, Canada.

1865. Walpole, Thomas, Messrs. Ross and Walpole, North Wall Iron Works, Dublin.

1877. Walton, James, 28 Maryon Road, Charlton.

1881. Warburton, John Seaton, 12 Lisgar Terrace, West Kensington, London, W.
1882. Ward, Thomas Henry, Messrs. Lee Howl Ward and Howl, Tipton.
1876. Ward, William Meese, Limerick Foundry, Great Bridge, Tipton.
1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Handsworth, near Birmingham.
1856. Wardle, Charles Wetherell, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds.
1882. Wardle, Edwin, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds.
1852. Warham, John R., Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.
1881. Warham, Richard Landor, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.
1882. Warsop, Henry, Clarendon Hotel, Nottingham.
1858. Waterhouse, Thomas, Claremont Place, Sheffield. (*Life Member.*)
1881. Watkins, Alfred, 62 South Street, Greenwich, S.E.
1862. Watkins, Richard, Messrs. Seaward and Co., Canal Iron Works, Millwall, London, E.
1882. Watson, Henry Burnett, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne.
1879. Watson, William Renny, Messrs. Mirrlees Tait and Watson, Engineers, Glasgow.
1877. Watts, John, Broad Weir Engine Works, Bristol.
1877. Waugh, John, Chief Engineer, Yorkshire Boiler Insurance and Steam Users' Co., Sunbridge Chambers, Bradford.
1878. Weatherhead, Patrick Lambert, 3 Chaussée Strasse, Berlin.
1862. Webb, Francis William, Locomotive Superintendent, London and North Western Railway, Crewe.
1884. Webb, Richard George, 60 Warwick Gardens, Kensington, London, W.
1883. Weck, Friedrich, Manager, Messrs. C. and W. Walker, Midland Iron Works, Donnington, near Newport, Shropshire.
1862. Wells, Charles, Moxley Iron and Steel Works, near Bilston.
1882. West, Charles Dickinson, Professor of Mechanical Engineering, Imperial College of Engineering, Tokio, Japan.
1876. West, Henry Hartley, Chief Surveyor, Underwriters' Registry for Iron Vessels, A13 Exchange Buildings, Liverpool.
1874. West, Nicholas James, Messrs. Harvey and Co., Hayle Foundry, Hayle.
1877. Western, Charles Robert, Messrs. Western and Co., Chaddesden Works, Derby; and Chaddesden Hill, Derby.

1877. Western, Maximilian Richard, care of Bombay Burmah Trading Corporation, Rangoon, British Burmah, India: (or care of Messrs. Western and Sons, 35 Essex Street, Strand, London, W.C.)

1862. Westmacott, Percy Graham Buchanan, Sir W. G. Armstrong Mitchell and Co., Elswick Engine Works, Newcastle-on-Tyne; and Benwell Hill, Newcastle-on-Tyne.

1880. Westmoreland, John William Hudson, 62 Dryden Street, Nottingham.

1867. Weston, Thomas Aldridge, Yale and Towne Manufacturing Co., 62 Reade Street, New York: (or care of J. C. Mewburn, 169 Fleet Street, London, E.C.)

1880. Westwood, Joseph, Jun., Messrs. Westwood Baillie and Co., London Yard Iron Works, Poplar, London, E.; and 39 Great Tower Street, London, E.C.

1883. Wharton, Henry E., Engineering Manager, Basford Gas Works, Nottingham.

1881. Wharton, William Augustus, Assistant Engineer, Nottingham Corporation Water Works, St. Peter's Gate, Nottingham.

1856. Wheeldon, Frederick R., Highfields Engine Works, Bilston; and Hough House, Waterloo Road, Wolverhampton.

1884. Whieldon, John Henry, River Trent Navigation, 17 Low Pavement, Nottingham.

1882. White, Alfred Edward, Borough Engineer's Office, Town Hall, Hull.

1874. White, Henry Watkins, 13 Barforth Road, Nunhead, London, S.E.

1876. Whiteley, William, Messrs. William Whiteley and Sons, Prospect Iron Works, Lockwood, Huddersfield.

1884. Whithard, Brooke Middlemore, 18 Cockspur Street, London, S.W.

1863. Whitley, Joseph, New British Iron Works, Corngreaves, near Birmingham.

1865. Whitley, Joseph, Railway Works, Hunslet Road, Leeds.

1869. Whittem, Thomas Sibley, Wyken Colliery, Coventry.

1847. Whitworth, Sir Joseph, Bart., D.C.L., LL.D., F.R.S., 44 Chorlton Street, Portland Street, Manchester; and Stancliffe, Matlock Bath; and 24 Great George Street, Westminster, S.W.

1878. Whytehead, Hugh Edward, 88 West Hill, Sydenham, London, S.E.

1878. Wicks, Henry, Superintendent, Messrs. Burn and Co., Howrah Iron Works, Howrah, Bengal, India: (or care of Dr. Wicks, 1 Park Parade, Westmorland Road, Newcastle-on-Tyne.)

1868. Wicksteed, Joseph Hartley, Messrs. Joshua Buckton and Co., Well House Foundry, Meadow Road, Leeds.

1878. Widmark, Harald Wilhelm, Helsingborgs Mekaniska Verkstad, Helsingborg, Sweden.

1868. Wigram, Reginald, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1881. Wigzell, Eustace Ernest, 37 Walbrook, London, E.C.
1884. Wilder, John, Yield Hall Foundry, Reading.
1874. Williams, David, Manager, Pontypool Iron and Tinplate Works, Pontypool.
1865. Williams, Edward, Cleveland Lodge, Middlesbrough.
1883. Williams, Edward Leader, Queen's Chambers, John Dalton Street, Manchester.
1884. Williams, John Begby, Messrs. William Gray and Co., Central Marine Engineering Works, West Hartlepool.
1884. Williams, John Rhys, Rhymney Iron Works, Rhymney, R.S.O., Monmouthshire.
1847. Williams, Richard, Patent Shaft Works, Wednesbury.
1881. Williams, William Freke Maxwell, 35 Queen Victoria Street, London, E.C.
1873. Williams, William Lawrence, 2 Westminster Chambers, Victoria Street, Westminster, S.W.
1883. Williamson, Richard, Messrs. Richard Williamson and Son, Iron Shipbuilding Yard, Workington.
1870. Willman, Charles, Exchange Place, Middlesbrough.
1883. Willmott, Arthur Wellesley Westmacott, 11 Rue St. Joseph, Antwerp.
1884. Willock, Capt. Harry Borlase, R.E., War Office, Whitehall, London, S.W.
1878. Wilson, Alexander, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.
1884. Wilson, Alexander, 46 Leyton Road, Forest Gate, London, E.
1882. Wilson, Alexander Basil, Holywood, Belfast.
1872. Wilson, Alfred, Gas Furnace Engineer, Stafford.
1859. Wilson, George, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.
1883. Wilson, George Prangley, Assistant Manager, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.
1867. Wilson, Henry, Phœnix Brass Works, Stockton-on-Tees.
1884. Wilson, James, Chief Engineer of the Daira Sanieh, Egypt; Cairo, Egypt.
1881. Wilson, John, Engineer, Great Eastern Railway, Liverpool Street Station, London, E.C.
1863. Wilson, John Charles, 5 Westminster Chambers, Victoria Street, Westminster, S.W.
1879. Wilson, Joseph William, Principal of School of Practical Engineering, Crystal Palace, Sydenham, London, S.E.
1880. Wilson, Robert, 24 Poultry, London, E.C.
1883. Wilson, Robert, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester.
1884. Wilson, Thomas, Manager, Wallsend Slipway and Engineering Works, Wallsend, near Newcastle-on-Tyne.

1873. Wilson, Thomas Sipling, British Vice-Consul, Brettesnœs, Lofoten Islands, Norway; and Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Leeds: (or care of Messrs. James Bischoff and Sons, 10 St. Helen's Place, London, E.C.)

1881. Wilson, Wesley William, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.

1867. Winby, Frederick Charles, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1872. Winstanley, Robert, Mining Engineer, 28 Deansgate, Manchester.

1859. Winter, Thomas Bradbury, 53 Moorgate Street, London, E.C.

1872. Wise, William Lloyd, 46 Lincoln's Inn Fields, London, W.C.

1871. Withy, Edward, Post Office, Auckland, New Zealand.

1884. Withy, Henry, Messrs. Withy and Co., Middleton Ship Yard, West Hartlepool.

1878. Wolfe, John Edward, care of G. W. Wucherer, H.B.M. Vice-Consul, Jaragua, Maceio, Brazil: (or care of Rev. Prebendary Wolfe, Arthington, Torquay.)

1878. Wolfenden, Richard, Chief Engineer, Chinese Cruiser "Yang Wei"; care of Chinese Customs Agency, Hong Kong, China; and 11 Grafton Street, Moss Side, Manchester.

1878. Wolfenden, Robert, Revenue Cutter "Ling Fêng," care of Commissioner of Customs, Amoy, China.

1882. Wolff, John Frederick, 43 Lavender Sweep, Clapham Common, London, S.W.

1881. Wood, Edward Malcolm, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1868. Wood, Lindsay, Mining Engineer, Southhill, near Chester-le-Street.

1884. Wood, Sidney Prescott, care of H. C. O. Little, Messrs. McKenzie and Holland, Vulcan Iron Works, Worcester.

1876. Wood, Thomas, Mining Engineer, North Hetton Collieries, Fence Houses.

1882. Woodall, Corbet, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1873. Woodhead, John Proctor, 54 John Dalton Street, Manchester.

1884. Woodward, William, Eastcroft Gas Works, Nottingham.

1874. Worsdell, Thomas William, Locomotive Superintendent, Great Eastern Railway, Stratford, London, E.

1884. Worssam, Charles Smith, Messrs. Samuel Worssam and Co., Oakley Works, Chelsea, London, S.W.

1877. Worssam, Henry John, Messrs. G. J. Worssam and Son, Wenlock Road, City Road, London, N.

1876. Worssam, Samuel William, Oakley Works, King's Road, Chelsea, London, S.W.

1860. Worthington, Samuel Barton, Resident Engineer, London and North Western Railway, Victoria Station, Manchester; and 12 York Place, Oxford Road, Manchester.

1866. Wren, Henry, Messrs. Henry Wren and Co., London Road Iron Works, Manchester.

1881. Wrench, John Mervyn, Resident Engineer, Scinde Punjaub and Delhi Railway, Lahore, Punjaub, India.

1881. Wright, Benjamin Frederick, Locomotive and Carriage Superintendent, Japanese Government Railways, Kobe, Japan: (or care of Messrs. Malcolm Brunker and Co., 22 St. Mary Axe, London, E.C.)

1870. Wright, George Benjamin, Tettenhall Road, Wolverhampton.

1878. Wright, Rev. George Howard, 21 Clanricarde Gardens, Bayswater, London, W.

1876. Wright, James, Messrs. Ashmore and White, Hope Iron Works, Bowesfield, Stockton-on-Tees.

1867. Wright, John Roper, Messrs. Wright Buttler and Co., Elba Steel Works, Gower Road, near Swansea.

1859. Wright, Joseph, Metropolitan Railway-Carriage and Wagon Co., Saltley Works, Birmingham; and 85 Gracechurch Street, London, E.C.

1860. Wright, Joseph, Neptune Forge, Chain and Anchor Works, Tipton; and Attercliffe, 42 Frederick Road, Edgbaston, Birmingham.

1878. Wright, William Barton, Locomotive Superintendent, Lancashire and Yorkshire Railway, Victoria Station, Manchester.

1871. Wrightson, Thomas, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.

1865. Wyllie, Andrew, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.

1883. Wyllie, Robert, Manager, Messrs. Thomas Richardson and Sons, Hartlepool Iron Works, Hartlepool.

1883. Wynne-Edwards, Thomas Alured, Agricultural Engineering Works, Denbigh.

1877. Wyvill, Frederic Christopher, 69 Old Street, London, E.C.

1878. Yates, Henry, Brantford, Ontario, Canada.

1882. Yates, Herbert Rushton, Assistant Engineer, Michigan Air Line Railway Extension, Pontiac, Michigan, United States: (or care of Henry Yates, Brantford, Ontario, Canada.)

1881. Yates, Louis Edmund Hasselts, Assistant Locomotive Superintendent, Northern Bengal State Railway, Saidpur, Bengal, India: (or care of Rev. H. W. Yates, 98 Lansdowne Place, Brighton.)

1880. Yates, William, Locomotive Works, Lancashire and Yorkshire Railway, Miles Platting, Manchester.

1879. Yeomans, David Maitland, American Finance Co., 5 and 7 Nassau Street, New York.

1880. York, Francis Colin, care of Messrs. Samuel York and Co., Snow Hill, Wolverhampton.

1879. Young, George Scholey, Messrs. T. A. Young and Son, Orchard Place, Blackwall, London, E.
1874. Young, James, Managing Engineer, Lambton Colliery Works, Fence Houses.
1879. Young, James, Low Moor Iron Works, near Bradford.
1881. Younger, Robert, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.

1880. Ziffer, Ferdinand Henry, Messrs. Ziffer and Walker, 6 Exchange Street, Manchester.

ASSOCIATES.

1880. Allen, William Edgar, Imperial Steel Works, Savile Street, Sheffield.
1880. Bagshawe, Washington, Monk Bridge Iron Works, Leeds.
1881. Barcroft, Henry, Bessbrook Spinning Works, County Armagh, Ireland.
1879. Clowes, Edward Arnott, Messrs. William Clowes and Sons, Duke Street, Stamford Street, London, S.E.
1867. Dewhurst, John Bonny, Bellevue Cotton Mills, Skipton.
1882. Drury, Robert Francis, George Street, Sheffield.
1883. Fairholme, Capt. Charles, R.N., Heberlein Self-acting Railway Brake Co., 9 Gracechurch Street, London, E.C.
1883. Fung Yee, Secretary, Chinese Legation, 49 Portland Place, London, W.
1865. Gössell, Otto, 41 Moorgate Street, London, E.C.
1878. Grosvenor, The Right Hon. Lord Richard De Aquila, M.P., 12 Upper Brook Street, Grosvenor Square, London, W.
1880. Haggie, David Henry, Wearmouth Rope Works, Sunderland.
1884. Hasluck, Paul Nooncree, 309 Regent Street, London, W.
1884. Jackson, Edward, Midland Railway-Carriage and Wagon Works, Birmingham.
1882. Jackson, William, Kingston Cotton Mill, Hull.
1859. Leather, John Towlerton, Leventhorpe Hall, near Leeds. (*Life Associate.*)
1884. Livesey, Joseph Montague, Stourton Hall, Horncastle; and Boyle Farm, Thames Ditton, Surrey.
1865. Longsdon, Alfred, 9 New Broad Street, London, E.C.
1881. Lowood, John Grayson, Gannister Works, Attercliffe Road, Sheffield.
1883. Macilraith, James, 182 Hope Street, Glasgow.
1860. Manby, Cordy, Messrs. Moore and Manby, Castle Street, Dudley.
1868. Matthews, Thomas Bright, Messrs. Turton Brothers and Matthews, Phœnix Steel Works, Sheffield.
1874. Paget, Berkeley, Low Moor Iron Office, 2 Laurence Pountney Hill, Cannon Street, London, E.C.
1865. Parry, David, Leeds Iron Works, Leeds.
1874. Pepper, Joseph Ellershaw, Clarence Iron Works, Leeds.
1884. Phillips, Richard Morgan, care of Messrs. Emile Des Marets and Co., 14 Stone Street, New York, United States.
1877. Render, Frederick, 12 St. Mary Street, Deansgate, Manchester.
1882. Ridehalgh, George John Miller, Fell Foot, Newby Bridge, Ulverston.
1884. Ripper, William, 30 New Porter Street, Broomhall, Sheffield.
1878. Roeckner, Carl Heinrich, 4 Royal Arcade, Newcastle-on-Tyne.
1883. Sandham, Henry, Keeper, Science and Art Department, South Kensington Museum, London, S.W.

1875. Schofield, Christopher J., Vitriol and Alkali Works, Clayton, near Manchester.

1884. Tilfourd, George, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1869. Varley, John, Leeds Forge, Leeds.

1875. Waslekar, Nanaji Narayan, 21 Old Boitokhana Bazar Road, Calcutta.

1878. Watson, Joseph, Patent Office, 25 Southampton Buildings, London, W.C.

1883. Williamson, Robert S., Cannock and Rugeley Collieries, Hednesford, near Stafford.

GRADUATES.

1884. Adam, Frank, Sir W. G. Armstrong Mitchell and Co., Elswick, Newcastle-on-Tyne.

1881. Alexander, Edward Disney, care of Rev. W. Hudson, Carlton Rectory, Worksop.

1874. Allen, Frank, Messrs. Allen Alderson and Co., Gracechurch Street, Alexandria: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1882. Allgood, Robert Lancelot, Ingram, Alnwick.

1880. Anderson, Edward William, Messrs. Easton and Anderson, Erith Iron Works, Erith, London, S.E.

1882. Anderson, William, North Eastern Railway, Locomotive Department, York.

1878. Appleby, Charles, Jun., Messrs. Appleby Brothers, 89 Cannon Street, London, E.C.; and East Greenwich Works, London, S.E.

1883. Appleby, Percy Vavasseur, Messrs. Appleby Brothers, East Greenwich Works, London, S.E.

1878. Armstrong, Joseph, Great Western Railway Works, Swindon.

1869. Bainbridge, Emerson, Nunnery Colliery Offices, New Haymarket, Sheffield.

1882. Barstow, Thomas Hulme, Assistant Engineer, Locomotive Department, Auckland Railway, Auckland, New Zealand.

1881. Beesley, David Stanley, Messrs. D. S. Beesley and Co., 89 Dartmouth Street, Birmingham.

1884. Bell, Robert Arthur, Kew, Surrey.

1880. Birkett, Herbert, Messrs. J. and E. Hall, Iron Works, Dartford.

1882. Blundstone, Samuel Richardson, 5 Clarence Villas, Moore Park Road, Walham Green, London, S.W.

1884. Bocquet, Harry, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1883. Booth, William Stanway, Messrs. H. B. Barlow and Co., Cornbrook Heald Works, Chester Road, Manchester.

1882. Bowles, Edward Wingfield, 86 Cambridge Street, Pimlico, London, S.W.

1878. Brooke, Arthur, General Post Office, Auckland, New Zealand.

1880. Buckle, William Harry Ray, Union Dock, Limehouse, London, E.

1878. Buddicom, Harry William, Moreton Villa, Abergavenny.

1879. Burnet, Lindsay, Moore Park Boiler Works, Govan, near Glasgow.

1884. Butler, Hugh Myddleton, Kirkstall Forge, near Leeds.

1883. Cairns, The Hon. Herbert John, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne.

1883. Clench, Frederick McDakin, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1881. Clench, Gordon McDakin, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1883. Clinkskill, Alfred Alphonse Rouff, Messrs. J. Copeland and Co., Pulteney Street Engine Works, Glasgow.

1883. Cotton, Henry Streatfeild, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.; and 1 c Vincent Square, Westminster, S.W.

1883. Cowan, Henry John Franklin, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1883. Cumming, Robert, Blarour, Kirkintilloch, near Glasgow.

1876. Davis, Joseph, Lancashire and Yorkshire Railway, Engineer's Office, Manchester.

1875. Dawson, Edward, Messrs. Brown and Adams, Guild Hall Chambers Cardiff.

1884. Dixon, John, Manchester Sheffield and Lincolnshire Railway, Locomotive Department, Gorton, Manchester.

1868. Dugard, William Henry, Messrs. Dugard Brothers, Vulcan Rolling Mills Bridge Street West, Summer Lane, Birmingham.

1875. Ffolkes, Martin William Brown, 28 Davies Street, Grosvenor Square, London, W.

1883. Gibbons, Charles Kenrick, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne.

1878. Greig, Alfred, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1882. Heath, Ashton Marler, London and South Western Railway, Locomotive Department, Nine Elms, London, S.W.

1877. Heaton, Arthur, Messrs. Heaton and Dugard, Metal and Wire Works, Shadwell Street, Birmingham.

1874. Hedley, Thomas, 92 Durning Road, Liverpool.

1883. Henderson, William, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1883. Hill, John Kershaw, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1867. Holland, George, Mechanical Department, Grand Trunk Railway, Montreal, Canada.

1884. Holt, Follett, 3 Devonshire Terrace, Portland Place, London, W.

1883. Howard, Harry James, Messrs. Colman's Mustard Mills, Carrow Works, Norwich.

1879. Howard, J. Harold, Britannia Iron Works, Bedford.

1883. Hulse, Joseph Whitworth, Messrs. Hulse and Co., Ordsal Tool Works, Regent Bridge, Salford, Manchester.

1880. Jenkins, Rhys, Patent Office, 25 Southampton Buildings, London, W.C.

1883. Keen, Francis Watkins, Patent Nut and Bolt Works, Smethwick, near Birmingham.

1884. King, Charles Philip, Messrs. Humphrys Tennant and Co., Deptford Pier, London, S.E.; and 57 Douglas Street, Deptford, London, S.E.

1883. Lander, Philip Vincent, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1881. Lawson, James Ibbs, New Zealand Railways, Dunedin, Otago, New Zealand.

1884. Lepan, René, Lead and Tin Rolling Mills and Pipe Works, Lille (Nord), France.

1879. Lowthian, George, 3 Victoria Mansions, Victoria Street, Westminster, S.W.

1881. Macdonald, Ranald Mackintosh, Messrs. Booth Macdonald and Co., Carlyle Engineering and Implement Works, Christchurch, New Zealand; and P.O. Box 89, Christchurch, New Zealand.

1883. Mackenzie, Thomas Brown, Messrs. J. Copeland and Co., Pulteney Street Engine Works, Glasgow; and 342 Duke Street, Glasgow.

1883. Malan, Ernest de Mérindol, Victoria Station, District Railway, London, S.W.

1868. Mappin, Frank, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.

1883. Marrack, Philip, R.N., Royal Naval College, Greenwich, S.E.

1882. Martindale, Warine Ben Hay, Dharwar, Deccan, India; and 21 Kensington Gardens Square, London, W.

1881. Milles, Robert Sydney, St. Margaret's, Staplehurst.

1867. Mitchell, John, Swaithe Colliery, Barnsley.

1868. Moor, William, Jun., Cross Lanes, Hetton-le-Hole, near Fence Houses.

1872. Napier, Robert Twentyman, Yoker, Dumbartonshire.

1878. Newall, John Walker, Forest Hall, Ongar, Essex.

1882. Noble, Saxton William Armstrong, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne.

1881. Norris, Moraston Ormerod, Assistant Engineer, Public Works Department, Madras: care of Messrs. Arbuthnot and Co., Madras.

1883. O'Connor, John Frederick, 16 Exchange Place, New York.

1883. Osborn, William Fawcett, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1881. Oswell, William St. John, Frankton House, Oswestry.

1883. Palchoudhuri, Bipradas, 35 Wellington Street, Calcutta.

1880. Paterson, Walter Saunders, Bombay Burmah Trading Corporation, Rangoon, British Burmah, India: (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1883. Peck, Walter, Engineer, Union Steamship Co., Port Chalmers, Otago, New Zealand.

1884. Philipson, William, Messrs. Atkinson and Philipson, 27 Pilgrim Street, Newcastle-on-Tyne.

1883. Pigott, Arthur Walter, Rathmines, Dublin.

1884. Reynolds, Thomas Blair, 5 Great George Street, Westminster, S.W.

1881. Rogers, Philip Powys, Assistant Engineer, Warda Coal State Railway, Warora, Central Provinces, India; care of Messrs. Grindlay Groom and Co., Bombay, India.

1884. Roux, Paul S., 138 Rue Amelot, Paris.

1882. Sanchez, Juan Emilio, 31 Rivadavia, Buenos Aires, Argentine Republic: (or care of Mateo Clark, 4 St. Mary Axe, London, E.C.)

1882. Scott, Charles Herbert, Bessemer Steel Works, Sheffield.

1881. Scott, Ernest, Close Works, Newcastle-on-Tyne.

1883. Simpson, Charles Liddell, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1879. Solly, Arthur John, Heathfield, Congleton.

1877. Spielmann, Marion Harry, 16 Porchester Terrace, Hyde Park, London, W.

1883. Spooner, Henry John, 311 Regent Street, London, W.

1884. Streatfeild, Mervyn Armytage, 8 Victoria Chambers, Westminster, S.W.

1883. Swale, Gerald, Anglo-Austrian Brush Electrical Co., Vienna.

1884. Taylor, Joseph, 2 Hewitt's Cottages, Edward Street, Canning Town, London, E.

1884. Taylor, Maurice, Pall Mall Club, Waterloo Place, London, S.W.

1884. Templeton, Edwin Arthur Slade, care of John C. Fell, 1 Queen Victoria Street, London, E.C.

1878. Waddington, John, Jun., 35 King William Street, London Bridge, London, E.C.

1882. Wailes, George Herbert, St. Andrews, Watford, Herts.

1884. Walker, Matthew, Cavendish Crescent North, The Park, Nottingham.

1884. Walker, Ralph Teasdale, Messrs. Easton and Anderson, Erith Iron Works, Erith, London, S.E.

1881. Walkinshaw, Frank, Hartley Grange, Winchfield.

1883. Westmacott, Henry Armstrong, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne.

1880. Weymouth, Francis Marten, 10 Garlinge Road, Cricklewood, London, N.W.

1879. Wood, Edward Walter Naylor, Engineer's Department, Great Indian Peninsula Railway, Bombay.

1880. Wood, John Mackworth, Engineer's Department, New River Water Works, Clerkenwell, London, E.C.

1882. Woollcombe, Reginald, Assistant Engineer, Public Works Department, India; care of Messrs. King King and Co., Bombay.

THE INSTITUTION OF MECHANICAL ENGINEERS.

Memorandum of Association.

August 1878.

1st. The name of the Association is "The Institution of Mechanical Engineers."

2nd. The Registered Office of the Association will be situate in England.

3rd. The objects for which the Association is established are :—

(A.) To promote the science and practice of Mechanical Engineering and all branches of mechanical construction, and to give an impulse to inventions likely to be useful to the Members of the Institution and to the community at large.

(B.) To enable Mechanical Engineers to meet and to correspond, and to facilitate the interchange of ideas respecting improvements in the various branches of mechanical science, and the publication and communication of information on such subjects.

(C.) To acquire and dispose of property for the purposes aforesaid.

(D.) To do all other things incidental or conducive to the attainment of the above objects or any of them.

4th. The income and property of the Association, from whatever source derived, shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly, by way of dividend, bonus, or otherwise howsoever, by way of profit to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them: Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any Member of the Association, or other person, in return for any services rendered to the Association, or prevent the giving of privileges to the Members of the Association in attending the meetings of the Association, or prevent the borrowing of money (under such powers as the Association and the Council thereof may possess) from any Member of the Association, at a rate of interest not greater than five per cent. per annum.

5th. The fourth paragraph of this Memorandum is a condition on which a licence is granted by the Board of Trade to the Association in pursuance of Section 23 of the Companies Act 1867. For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which shall be duly observed by the Association.

6th. If the Association act in contravention of the fourth paragraph of this Memorandum, or of any such further conditions, the liability of every Member of the Council shall be unlimited; and the liability of every Member of the Association who has received any such dividend, bonus, or other profit as aforesaid, shall likewise be unlimited.

7th. Every Member of the Association undertakes to contribute to the Assets of the Association in the event of the same being wound up during the time that he is a Member, or within one

year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a Member, and of the costs, charges, and expenses for winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding Five Shillings, or in case of his liability becoming unlimited such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

8th. If upon the winding up or dissolution of the Association there remains, after the satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the Members of the Association, but shall be given or transferred to some other Institution or Institutions having objects similar to the objects of the Association, to be determined by the Members of the Association at or before the time of dissolution; or in default thereof, by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter.

Articles of Association.

August 1878.

INTRODUCTION.

Whereas an Association (hereinafter called "the existing Institution") called "The Institution of Mechanical Engineers" has long existed for objects similar to the objects expressed in the Memorandum of Association of the Association (hereinafter called "the Institution") to which these Articles apply, and the existing Institution consists of Members, Graduates, Associates, and Honorary Life Members, and is possessed of books, drawings, and property used for the objects aforesaid;

And whereas the Institution is formed for furthering and extending the objects of the existing Institution, by a registered Association, under the Companies Acts 1862 and 1867; and terms used in these Articles are intended to have the same respective meanings as they have when used in those Acts, and words implying the singular number are intended to include the plural number, and *vice versâ*;

Now therefore it is hereby agreed as follows:—

CONSTITUTION.

1. For the purpose of registration the number of Members of the Institution is unlimited.

MEMBERS.

2. The subscribers of the Memorandum of Association, and such other persons as shall be admitted in accordance with these Articles, and none others, shall be Members of the Institution, and be entered on the register as such.

3. Any person may become a Member of the Institution who, being a Member of the existing Institution, shall agree to transfer his membership of the existing Institution, and all rights and obligations incidental thereto, to the Institution, and to be registered as a Member of the Institution accordingly.

4. Any person may become a Member of the Institution who shall be qualified and elected as hereinafter mentioned, and shall agree to become such Member, and shall pay the entrance fee and first subscription accordingly.

5. The rights and privileges of every Member of the Institution shall be personal to himself, and shall not be transferable or transmissible by his own act or by operation of law.

QUALIFICATION AND ELECTION OF MEMBERS.

6. The qualification of Members shall be prescribed by the Bye-laws from time to time in force, as provided by the Articles.

7. The election of Members shall be conducted as prescribed by the Bye-laws from time to time in force, as provided by the Articles.

GRADUATES, ASSOCIATES, AND HONORARY LIFE MEMBERS.

8. Any person may become a Graduate, Associate, or Honorary Life Member of the Institution, who, being already a Graduate, Associate, or Honorary Life Member of the existing Institution, shall agree to transfer his interest in the existing Institution, and all rights and obligations incidental thereto, to the Institution.

9. The Institution may admit such other persons as may be hereafter qualified and elected in that behalf as Graduates, Associates, and Honorary Life Members respectively of the Institution, and may confer upon them such privileges as shall be prescribed by the Bye-laws from time to time in force, as provided by the Articles: Provided that no Graduate, Associate, or Honorary Life Member shall be deemed to be a Member within the meaning of the Articles.

10. The qualification and mode of election of Graduates, Associates, and Honorary Life Members, shall be prescribed by the Bye-laws from time to time in force, as provided by the Articles.

ENTRANCE FEES AND SUBSCRIPTIONS.

11. The Entrance Fees and Subscriptions of Members, Graduates, and Associates, shall be prescribed by the Bye-laws from time to time in force, as provided by the Articles: Provided that no Entrance Fee shall be payable by a Member, Graduate, or Associate of the existing Institution.

EXPULSION.

12. If any Member, Graduate, or Associate shall leave his subscription in arrear for two years, and shall fail to pay such arrears within three months after a written application has been sent to him by the Secretary, his name may be struck off the list of Members, Graduates, or Associates, as the case may be, by the Council, at any time afterwards, and he shall thereupon cease to

have any rights as a Member, Graduate, or Associate, but he shall nevertheless continue liable to pay the arrears of subscription due at the time of his name being so struck off: Provided always, that this regulation shall not be construed to compel the Council to remove any name if they shall be satisfied the same ought to be retained.

13. The Council may refuse to continue to receive the subscriptions of any person who shall have wilfully acted in contravention of the regulations of the Institution, or who shall in the opinion of the Council have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution; and may remove his name from the list of Members, Graduates, or Associates (as the case may be), and such person shall thereupon cease to be a Member, Graduate, or Associate (as the case may be) of the Institution.

GENERAL MEETINGS.

14. The first General Meeting shall be held on such day, within four months of the registration of the Institution, as the Council shall determine. Subsequent General Meetings shall consist of the Ordinary Meetings, the Annual General Meeting, and of Special Meetings as hereinafter defined.

15. The Annual General Meeting shall take place in London in one of the first four months of every year. The Ordinary Meetings shall take place at such times and places as the Council shall determine.

16. A Special Meeting may be convened at any time by the Council, and shall be convened by them whenever a requisition signed by twenty Members of the Institution, specifying the object of the Meeting, is left with the Secretary. If for fourteen days after the delivery of such requisition a Meeting be not convened in accordance therewith, the Requisitionists or any twenty Members

of the Institution may convene a Special Meeting in accordance with the requisition. All Special Meetings shall be held in London.

17. Seven clear days' notice of every Meeting, specifying generally the nature of any special business to be transacted at any Meeting, shall be given to every Member of the Institution, and no other special business shall be transacted at such Meeting; but the non-receipt of such notice shall not invalidate the proceedings of such Meeting. No notice of the business to be transacted (other than such ballot lists as may be requisite in case of elections) shall be required in the absence of special business.

18. Special business shall include all business for transaction at a Special Meeting, and all business for transaction at every other Meeting, with the exception of the reading and confirmation of the Minutes of the previous Meeting, the election of Members, Graduates, and Associates, and the reading and discussion of communications as prescribed by the Bye-laws, or any regulations of the Council made in accordance with the Bye-laws.

PROCEEDINGS AT GENERAL MEETINGS.

19. Twenty Members shall constitute a quorum for the purpose of a Meeting other than a Special Meeting. Thirty Members shall constitute a quorum for the purposes of a Special Meeting.

20. If within thirty minutes after the time fixed for holding the Meeting a quorum is not present, the Meeting shall be dissolved, and all matters which might, if a quorum had been present, have been done at a Meeting (other than a Special Meeting) so dissolved, may forthwith be done on behalf of the Meeting by the Council.

21. The President shall be Chairman at every Meeting, and in his absence one of the Vice-Presidents; and in the absence of all Vice-Presidents a Member of Council shall take the chair; and if

no Member of Council be present and willing to take the chair, the Meeting shall elect a Chairman.

22. The decision of a General Meeting shall be ascertained by show of hands, unless, after the show of hands, a poll is forthwith demanded, and by a poll when a poll is thus demanded. The manner of taking a show of hands or a poll shall be in the discretion of the Chairman, and an entry in the Minutes, signed by the Chairman, shall be sufficient evidence of the decision of the General Meeting. Each Member shall have one vote and no more. In case of equality of votes the Chairman shall have a second or casting vote: Provided that this Article shall not interfere with the provisions of the Bye-laws as to election by ballot.

23. The acceptance or rejection of votes by the Chairman shall be conclusive for the purpose of the decision of the matter in respect of which the votes are tendered: Provided that the Chairman may review his decision at the same Meeting if any error be then pointed out to him.

BYE-LAWS.

24. The Bye-laws set forth in the schedule to these Articles, and such altered and additional Bye-laws as shall be added or substituted as hereinafter mentioned, shall regulate all matters by the Articles left to be prescribed by the Bye-laws, and all matters which consistently with the Articles shall be made the subject of Bye-laws. Alterations in, and additions to, the Bye-laws, may be made only by resolution of the Members at an Annual General Meeting, after notice of the proposed alteration or addition announced at the previous Ordinary Meeting, and not otherwise.

COUNCIL.

25. The Council of the Institution shall be chosen from the Members only, and shall consist of one President, six Vice-Presidents, fifteen ordinary Members of Council, and of the Past-

Presidents; and the first Council (which shall include Past-Presidents of the existing Institution) shall be as follows:—

PRESIDENT.

John Robinson	Manchester.

PAST-PRESIDENTS.

Sir William G. Armstrong, C.B., D.C.L., LL.D., F.R.S.	Newcastle-on-Tyne.
Frederick J. Bramwell, F.R.S.	London.
Thomas Hawksley	London.
James Kennedy	Liverpool.
John Penn, F.R.S.	London.
John Ramsbottom	Manchester.
C. William Siemens, D.C.L., F.R.S.	London.
Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S. .	Manchester.

VICE-PRESIDENTS.

I. Lowthian Bell, M.P., F.R.S.	Northallerton.
Charles Cochrane	Stourbridge.
Edward A. Cowper	London.
Charles P. Stewart	London.
Francis W. Webb	Crewe.
Percy G. B. Westmacott	Newcastle-on-Tyne.

COUNCIL.

Daniel Adamson	Manchester.
John Anderson, LL.D., F.R.S.E.	London.
Henry Bessemer	London.
Henry Chapman	London.
Edward Easton	London.
David Greig	Leeds.
Jeremiah Head	Middlesbrough.
Thomas R. Hetherington	Manchester.
Henry H. Laird	Birkenhead.
William Menelaus	Dowlais.
Arthur Paget	Loughborough.
John Penn, Jun.	London.
George B. Rennie	London.
William Richardson	Oldham.
John C. Wilson	Bristol.

26. The first Council shall continue in office till the Annual General Meeting in the year 1879. The President, two Vice-Presidents, and five Members of the Council (other than Past-Presidents), shall retire at each succeeding Annual General Meeting, but shall be eligible for re-election. The Vice-Presidents and Members of Council to retire each year shall, unless the Council agree amongst themselves, be chosen from those who have been longest in office, and in cases of equal seniority shall be determined by ballot.

27. The election of a President, Vice-Presidents, and Members of the Council, to supply the place of those retiring at the Annual General Meeting, shall be conducted in such manner as shall be prescribed by the Bye-laws from time to time in force, as provided by the Articles.

28. The Council may supply any casual vacancy in the Council (including any casual vacancy in the office of President) which shall occur between one Annual General Meeting and another, and the President or Members of the Council so appointed by the Council shall retire at the succeeding Annual General Meeting. Vacancies not filled up at any such Meeting shall be deemed to be casual vacancies within the meaning of this Article.

OFFICERS.

29. The Treasurer, Secretary, and other employés of the Institution shall be appointed and removed in the manner prescribed by the Bye-laws from time to time in force, as provided by the Articles. Subject to the express provisions of the Bye-laws the officers and servants of the Institution shall be appointed and removed by the Council.

30. The powers and duties of the officers of the Institution shall (subject to any express provision in the Bye-laws) be determined by the Council.

POWERS AND PROCEDURE OF COUNCIL.

31. The Council may regulate their own procedure, and delegate any of their powers and discretions to any one or more of their body, and may determine their own quorum: if no other number is prescribed, three Members of Council shall form a quorum.

32. The Council shall acquire the property of the existing Institution, and shall manage the property, proceedings, and affairs of the Institution, in accordance with the Bye-laws from time to time in force.

33. The Treasurer may, with the consent of the Council, invest in the name of the Institution any moneys not immediately required for the purposes of the Institution in or upon any of the following investments (that is to say):—

(A.) The Public Funds, or Government Stocks of the United Kingdom, or of any Foreign or Colonial Government guaranteed by the Government of the United Kingdom.

(B.) Real or Leasehold Securities, or in the purchase of real or leasehold properties in Great Britain or Ireland.

(C.) Debentures, Debenture Stock, or Guaranteed or Preference Stock, of any Company incorporated by special Act of Parliament, the ordinary Shareholders whereof shall at the time of such investment be in actual receipt of half-yearly or yearly dividends.

(D.) Stocks, Shares, Debentures, or Debenture Stock of any Railway, Canal, or other Company, the undertaking whereof is leased to any Railway Company at a fixed or fixed minimum rent.

(E.) Stocks, Shares, or Debentures of any East Indian Railway or other Company, which shall receive a contribution from Her Majesty's East Indian Government of a fixed annual percentage on their capital, or be guaranteed a fixed annual dividend by the same Government.

(F.) The security of rates levied by any corporate body empowered to borrow money on the security of rates, where such borrowing has been duly authorised by Act of Parliament.

34. The Council may, with the authority of a resolution of the Members in General Meeting, borrow moneys for the purposes of the Institution on the security of the property of the Institution.

35. No act done by the Council, whether *ultra vires* or not, which shall receive the express or implied sanction of the Members of the Institution in General Meeting, shall be afterwards impeached by any Member of the Institution on any ground whatsoever, but shall be deemed to be an act of the Institution.

NOTICES.

36. A notice may be served by the Council of the Institution upon any Member, Graduate, Associate, or Honorary Life Member, either personally or by sending it through the post in a prepaid letter addressed to such Member, Graduate, Associate, or Honorary Life Member, at his registered place of abode.

37. Any notice, if served by post, shall be deemed to have been served at the time when the letter containing the same would be delivered in the ordinary course of the post, and in proving such service it shall be sufficient to prove that the letter containing the notice was properly addressed and put into the post office.

38. No Member, Graduate, Associate, or Honorary Life Member, not having a registered address within the United Kingdom shall be entitled to any notice; and all proceedings may be had and taken without notice to such Member in the same manner as if he had had due notice.

Bye-laws.

(*Last Revision*, 1884.)

MEMBERSHIP.

1. Members, Graduates, Associates, and Honorary Life Members of the existing Institution, may, upon signing and forwarding to the Secretary of the Institution a claim according to Form D in the Appendix, become Members, Graduates, Associates, or Honorary Life Members respectively of the Institution without election or payment of entrance fees.

2. Candidates for admission as Members must be Engineers not under twenty-four years of age, who may be considered by the Council to be qualified for election.

3. Candidates for admission as Graduates must be Engineers holding subordinate situations and not under eighteen years of age; and they may afterwards be admitted as Members at the discretion of the Council.

4. Candidates for admission as Associates must be gentlemen not under twenty-four years of age, who from their scientific attainments or position in society may be considered eligible by the Council.

5. The Council shall have the power to nominate as Honorary Life Members gentlemen of eminent scientific acquirements, who in their opinion are eligible for that position.

6. The Members, Graduates, Associates, and Honorary Life Members shall have notice of and the privilege to attend all Meetings, but Members only shall be entitled to vote thereat.

ENTRANCE FEES AND SUBSCRIPTIONS.

7. An Entrance Fee of £2 shall be paid by each Member, except Members of the existing Institution, who shall pay no Entrance Fee, and Graduates admitted as Members, who shall pay an Entrance Fee of £1. Each Member shall pay an Annual Subscription of £3.

8. An Entrance Fee of £1 shall be paid by each Graduate, except Graduates of the existing Institution, who shall pay no Entrance Fee. Each Graduate shall pay an Annual Subscription of £2.

9. An Entrance Fee of £2 shall be paid by each Associate, except Associates of the existing Institution, who shall pay no Entrance Fee. Each Associate shall pay an Annual Subscription of £3.

10. All Subscriptions shall be payable in advance, and shall become due on the 1st day of January in each year; and the first Subscription of Members, Graduates, and Associates, shall date from the 1st day of January in the year of their election.

ELECTION OF MEMBERS, GRADUATES, AND ASSOCIATES.

11. A recommendation for admission according to Form A in the Appendix shall be forwarded to the Secretary, and by him be laid before the next Meeting of the Council. The recommendation must be signed by not less than five Members if the application be for admission as a Member or Associate, and by three Members if it be for a Graduate.

12. All Elections shall take place by ballot, three-fifths of the votes given being necessary for election.

13. All applications for admission shall be communicated by the Secretary to the Council for their approval previous to being

inserted in the ballot list for election, and the approved ballot list shall be signed by the President and forwarded to the Members. The ballot list shall specify the name, occupation, and address of the Candidates, and also by whom proposed and seconded. The lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

14. The Elections shall take place at the General Meetings only.

15. When the proposed Candidate is elected, the Secretary shall give him notice thereof according to Form B; but his name shall not be added to the list of Members, Graduates, or Associates of the Institution until he shall have paid his Entrance Fee and first Annual Subscription, and signed the Form C in the Appendix.

16. In case of non-election, no mention thereof shall be made in the Minutes, nor any notice given to the unsuccessful Candidate.

17. A Graduate or Associate desirous of being transferred to the class of Members shall forward to the Secretary a recommendation according to Form E in the Appendix, signed by not less than five Members, which shall be laid before the next meeting of Council for their approval. On their approval being given, the Secretary shall notify the same to the Candidate according to Form F if an Associate, and according to Form G if a Graduate; but his name shall not be added to the list of Members until he shall have signed the Form H, and, if a Graduate, shall have paid £1 additional entrance fee, and £1 additional subscription for the current year.

ELECTION OF PRESIDENT, VICE-PRESIDENTS, AND MEMBERS OF COUNCIL.

18. Candidates shall be put in nomination at the General Meeting preceding the Annual General Meeting, when the Council are to present a list of their retiring Members who offer themselves for re-election; any Member shall then be entitled to add to the

list of Candidates. The ballot list of the proposed names shall be forwarded to the Members. The ballot lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

APPOINTMENT AND DUTIES OF OFFICERS.

19. The Treasurer shall be a Banker, and shall hold the uninvested funds of the Institution, except the moneys in the hands of the Secretary for current expenses. He shall be appointed by the Members at a General or Special Meeting, and shall hold office at the pleasure of the Council.

20. The Secretary of the Institution shall be appointed as and when a vacancy occurs by the Members at a General or Special Meeting, and shall be removable by the Council upon six months' notice from any day. The Secretary shall give the same notice. The Secretary shall devote the whole of his time to the work of the Institution, and shall not engage in any other business or profession.

21. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all meetings of the Institution, and of the Council, and of Committees; to take minutes of the proceedings of such meetings; to read the minutes of the preceding meetings, and all communications that he may be ordered to read; to superintend the publication of such papers as the Council may direct; to have the charge of the library; to direct the collection of the subscriptions, and the preparation of the account of expenditure of the funds; and to present all accounts to the Council for inspection and approval. He shall also engage (subject to the approval of the Council) and be responsible for all persons employed under him, and set them their portions of work and duties. He shall conduct the ordinary business of the Institution, in accordance with the Articles and Bye-laws and the directions of the President and Council; and shall refer to the

President in any matters of difficulty or importance, requiring immediate decision.

MISCELLANEOUS.

22. All Papers shall be submitted to the Council for approval, and after their approval shall be read by the Secretary at the General Meetings, or by the Author with the consent of the Council.

23. All books, drawings, communications, &c., shall be accessible to the Members of the Institution at all reasonable times.

24. All communications to the Meetings shall be the property of the Institution, and be published only by the authority of the Council.

25. None of the property of the Institution—books, drawings, &c.—shall be taken out of the premises of the Institution without the consent of the Council.

26. All donations to the Institution shall be enumerated in the Annual Report of the Council presented to the Annual General Meeting.

27. The General Meetings shall be conducted as far as practicable in the following order :—

1st. The Chair to be taken at such hour as the Council may direct from time to time.

2nd. The Minutes of the previous Meeting to be read by the Secretary, and, after being approved as correct, to be signed by the Chairman.

3rd. The Ballot Lists, previously opened by the Council, to be presented to the Meeting, and the new Members, Graduates, and Associates elected to be announced.

4th. Papers approved by the Council to be read by the Secretary, or, with the consent of the Council, by the Author.

28. Each Member shall have the privilege of introducing one friend to any of the Meetings; but, during such portion of any meeting as may be devoted to any business connected with the management of the Institution, visitors shall be requested by the Chairman to withdraw, if any Member asks that this shall be done.

29. Every Member, Graduate, Associate, or Visitor, shall write his name and residence in a book to be kept for the purpose, on entering each Meeting.

30. The President shall ex officio be Member of all Committees of Council.

31. Seven clear days' notice at least shall be given of every meeting of the Council. Such notice shall specify generally the business to be transacted by the meeting. No business involving the expenditure of the funds of the Institution (except by way of payment of current salaries and accounts) shall be transacted at any Council meeting unless specified in the notice convening the meeting.

32. The Council shall present the yearly accounts to the Members at the Annual General Meeting, after being audited by a professional accountant.

33. In the case of Members, Associates, or Graduates, elected in the last three months of any year, the first subscription shall cover both the year of election and the succeeding year.

34. No Proceedings or Ballot Lists shall be sent to Members, Associates, or Graduates, who are in arrear with their subscriptions more than twelve months.

35. Any Member wishing to have a copy of the Papers sent to him for consideration beforehand can do so by sending in his name once in each year to the Secretary; and a copy of all Papers shall then be forwarded to him as early as possible prior to the date of the Meeting at which they are intended to be read.

36. At any Meeting of the Institution any Member shall be at liberty to re-open the discussion upon any Paper which has been read or discussed at the preceding Meeting; provided that he signifies his intention to the Secretary at least one month previously to the Meeting, and that the Council decide to include it in the notice of the Meeting as part of the business to be transacted.

APPENDIX.

FORM A.

Mr. being of the required age, and desirous of admission into the Institution of Mechanical Engineers, we, the undersigned, from our personal knowledge, propose and recommend him as a proper person to become a thereof.

Witness our hands, this day of

Members.

FORM B.

Sir,—I have to inform you that on the you were elected a of the Institution of Mechanical Engineers. In conformity with the rules, your election cannot be confirmed until the enclosed form be returned to me with your signature, and until your Entrance Fee and first Annual Subscription be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the election will become void.

I am, Sir,

Your obedient servant,

Secretary.

FORM C.

I, the undersigned, being elected a of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they are now formed or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

FORM D.

As a of the Institution of Mechanical Engineers, I claim to become a of the Association incorporated under the same name.

Please register me as a

FORM E.

Mr. being of the required age, and desirous of being transferred into the class of Members of the Institution, we, the undersigned, from our personal knowledge, recommend him as a proper person to become a Member of the Institution of Mechanical Engineers.

FORM F.

SIR,—I have to inform you that the Council have approved of your being transferred to the class of Members of the Institution of Mechanical Engineers. In conformity with the rules, your transference cannot be confirmed until the enclosed form be returned to me with your signature. If this be not received within two months from the present date, the transference will become void.

I am, Sir,

Your obedient servant,

Secretary.

FORM G.

SIR,—I have to inform you that the Council have approved of your being transferred to the class of Members of the Institution of Mechanical Engineers. In conformity with the rules, your transference cannot be confirmed until the enclosed form be returned to me with your signature, and until your additional Entrance Fee (£1) and additional Annual Subscription (£1) be paid for the current year. If these be not received within two months from the present date, the transference will become void.

I am, Sir,

Your obedient servant,

Secretary.

FORM H.

I, the undersigned, having been transferred to the class of Members of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they now exist, or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

Institution of Mechanical Engineers.

PROCEEDINGS.

JANUARY 1884.

The THIRTY-SEVENTH ANNUAL GENERAL MEETING of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Thursday, 24th January, 1884, at Half-past Seven o'clock p.m.; PERCY G. B. WESTMACOTT, Esq., Retiring President, in the chair, succeeded by I. LOWTHIAN BELL, Esq., F.R.S., President elected at the Meeting.

The Minutes of the last Meeting were read, and were ordered to be corrected.

The PRESIDENT announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and the following New Members and Graduates were found to be duly elected :—

MEMBERS.

LÉON JOSEPH BIKA,	Brussels.
WILLIAM LOCKHART BONE,	Manchester.
JOHN COTTON,	Bradford.
JOHN CRIGHTON,	Manchester.
BARNARD JOHN CURETON,	Birmingham.
ROBERT DAVISON,	Glasgow.
FREDERICK GEORGE BROOKE FOX,	Prome, Burmah.
ALBERT FRANCIS HALL,	Boston, U.S.
FRANK EDWARD HOYLE,	Bahia.
JOHN KIRKALDY,	London.
ARTHUR HILL LEAKE,	Brisbane.
ANDREW LINTON LOGAN,	St. Petersburg.

WILLIAM McONIE, JUN., ...	Glasgow.
BENJAMIN THEOPHILUS MOORE, . . .	Teddington.
ANDREW LOUIS PAUL, ...	London.
LOUIS MARIE JOSEPH POILLON, . . .	Paris.
SAMUEL PUPLETT, ...	Birmingham.
JOSÉ MARIA DE CHERMONT RODRIGUES, .	Liége.
WILLIAM DUNDAS SCOTT-MONCRIEFF, .	London.
WILLIAM COPLEY SHACKLEFORD, . . .	Lancaster.
CHARLES STRONGE, ...	London.
BROOKE MIDDLEMORE WHITHARD, . .	London.
JOHN WILDER, ...	Reading.
JOHN BEGLEY WILLIAMS, ...	West Hartlepool.

GRADUATES.

JOHN DIXON, ...	Manchester.
THOMAS BLAIR REYNOLDS, ...	London.
JOSEPH TAYLOR, ...	London.
MATTHEW WALKER, ...	Nottingham.

The following Annual Report of the Council was then read :—

ANNUAL REPORT OF COUNCIL.

1884.

The Council have pleasure in laying the following Annual Report before the Meeting, on this occasion of the Thirty-seventh Anniversary of the Institution.

At the end of the year 1883 the total number of names of all classes on the roll of the Institution was 1440, as compared with 1370 at the corresponding period of the previous year. The increase arises as follows :—there were added to the register within the year 113 names of all classes; there were lost from the register by deceases 22 names of all classes, and by resignation or removal 21 names of all classes.

The following seven Graduates have been transferred by the Council, in the course of the year, to the class of Members:—

PERCY BENHAM,	London.
T. SMITH BRIGHT,	Carmarthen.
J. N. DADY,	Bombay.
HUGH NETTLEFOLD,	Birmingham.
HERBERT G. SHEPPARD,	London.
ARTHUR TAYLOR,	Pontgibaud.
F. COLIN YORK,	Buenos Ayres.

The following Deceases of Members of the Institution have occurred during the past year:—

CHARLES BERGERON,	London.
AMBROSE EDMUND BUTLER,	Kirkstall.
PROSPER CLOSSON,	Paris.
JOHN J. DERHAM,	Blackburn.
EDWARD DODSON (Associate),	Sheffield.
BENJAMIN SAMUEL FISHER,	Highbridge.
JOSIAH GIMSON,	Leicester.
JOHN INGLIS,	Hong Kong.
JABEZ JAMES,	London.
JOHN LENNOX KINCAID JAMIESON,	Glasgow.
JOSEPH JESSOP,	Leicester.
JAMES GASCOIGNE LYNDE,	Manchester.
THOMAS WILLIAM RUMBLE,	London.
JOHN FREDERICK SEDDON,	Accrington.
JOSEPH SHUTTLEWORTH,	Lincoln.
SIR WILLIAM SIEMENS, D.C.L., F.R.S., &c.,	London.
JOHN HENRY SOKELL (Associate),	Leeds.
THOMAS SAMUEL SPECK,	London.
JOHN HENRY STOREY,	Manchester.
RICHARD TAYLOR,	London.
THOMAS WHEATLEY,	Wigtown.
LAMPLUGH WICKHAM WICKHAM,	Low Moor.
ROBERT WILKINSON (deceased 1882),	Antigua.
OWEN WRIGHT,	Oldbury.

Amongst these, special mention must be made of Sir William Siemens, D.C.L., F.R.S., not merely as having been a Past-President of the Institution, but also as having contributed most active Members of the Institution, and as having contributed

no less than thirteen papers to its Proceedings. In these some of his most brilliant inventions, such as the Chronometric Governor, the Water Meter, the Regenerative Gas Furnace, &c., were first fully described, and they will always remain among the most valuable documents preserved in the records of the Institution. A special resolution of condolence was passed by the Council, on their first meeting subsequent to the funeral, and is about to be presented to Lady Siemens (see page 8).

The following gentlemen have ceased to be Members of the Institution during the past year:—

CHARLES JAMES ALLPORT,	London.
THOMAS OLDHAM BENNETT,	Melbourne.
WILLIAM CARSON,	Birkenhead.
JAMES HART,	London.
HENRY HUGHES,	Loughborough.
HENRY JAMES MADGE,	Calcutta.
ALFRED UPWARD,	London.

In addition there have been fourteen resignations of Membership during the year.

The Accounts for the year 1883, having been passed by the Finance Committee, and having been audited by Messrs. Robert A. McLean and Co., Public Accountants, are now submitted to the Members (*see Appendix I.*, pp. 10–13). It will be seen that the receipts for the year have been £4690 1*s.* 5*d.*, while the expenditure has been £4196 12*s.* 3*d.*, showing a balance of receipts over expenditure of £493 9*s.* 2*d.* A Balance Sheet is also appended, showing the financial position of the Institution at the end of the year to be thoroughly satisfactory. It will be seen that the total investments and other assets amounted to £15,050 15*s.* 3*d.*, and that the liabilities were *nil*, the capital of the Institution at the end of the year being therefore £15,050 15*s.* 3*d.* The greater part of this, as will be seen, is invested in Four per cent. Railway Debenture Stocks, registered in the name of the Institution, including the sum of £999 13*s.* 10*d.* invested during the year.

At the Birmingham Meeting it was announced by the President that the Council proposed to present to the Assistant Secretary, on

the occasion of his leaving the Institution, an honorarium of £1000, a course which they felt sure would meet with the approbation of the Members. They now ask the approval of the Members for this arrangement.

With regard to Research, the important series of experiments conducted by the Committee on Friction were laid before the Members at the last Meeting in Birmingham, and produced a discussion which will be renewed on the present occasion. The Council regret that the removal of the Works where the experiments were performed to another locality has necessarily occasioned a delay in their progress; but they are happy to announce that this delay is now at an end, and that the experiments will be immediately renewed by Mr. Tower, with the facilities offered by Mr. Tomlinson as before. The thanks of the Institution are especially due to the latter gentleman for the attention and care he has bestowed on the matter.

With regard to Steel, the Council regret to find that, owing to the difficulties existing in the preparation of suitable material, the results during the past year have not been so conclusive as Sir Frederick Abel had hoped to make them; they are nevertheless full of interest, and will be described in a report to be read at a future meeting by that gentleman. The Members will feel that their thanks are due to Sir Frederick Abel for having found time in the midst of his many other duties to advance this important research; and they should also be paid to Mr. Arthur Paget, the Landore Siemens Steel Co., and Messrs. Wilson Hawksworth Ellison & Co. of Sheffield, for kindly supplying the materials for the purpose of analysis.

With regard to Riveting, the experiments mentioned in the last Annual Report have been carried out, and a report of them is being prepared by Professor Kennedy for circulation among the Members. The thanks of the Committee are still due to Professor Kennedy for his labours in this direction, and also to the Mersey Harbour Board, to their Engineer, Mr. G. F. Lyster, and to Mr. Le Mesurier, the Superintendent of their testing works at Birkenhead, for the free use of their testing machine for the purpose of the experiments.

As the courses of experiment on the three subjects originally selected are drawing towards completion, the Council are taking steps to institute research on other questions of interest to engineers.

The following Donations to the Library of the Institution have been received during the past year, for which the Council have the pleasure of expressing their thanks to the Donors. (For List of Donations see *Appendix II.*, pp. 14–19.) Feeling the great desirability of enlarging and improving the Library, the Council again invite the Members to make donations of books, original pamphlets, or reports, and in particular of any records of experiments or researches made by themselves or their friends.

The Meetings held in 1883 were the Annual General Meeting and the Spring Meeting, both in London; the Summer Meeting in Belgium; and the Autumn Meeting at Birmingham. The List of Papers, as published in the Proceedings, is as follows:—

Report on further Experiments bearing upon the question of the Condition in which Carbon exists in Steel; by Professor F. A. Abel, C.B., F.R.S.

On the Molecular Rigidity of Tempered Steel; by Professor D. E. Hughes, F.R.S.

On the Working of Blast Furnaces, with special reference to the Analysis of the Escaping Gases; by Mr. Charles Cochrane.

On the St. Gothard Tunnel; by Herr E. Wendelstein.

On the Strength of Shafting when exposed both to Torsion and to End Thrust; by Professor A. G. Greenhill.

On some modern systems of Cutting Metals; by Mr. W. Ford Smith.

On Improvements in the Manufacture of Coke; by Mr. John Jameson.

On the History of the Iron and Coal Industries in the Liége district; by M. Édouard de Laveleye.

On the Manufacture of Zinc in Belgium; by M. St. Paul de Sinçay.

On the Manufacture of Sugar in Belgium; by M. A. Melin.

On the application of Electricity to the Working of Coal Mines; by Mr. Alan C. Bagot.

On Compound Locomotive Engines; by Mr. Francis W. Webb.

On the Construction and Working of the St. Gothard Railway; by Herr E. Wendelstein.

On the New Harbour Works at Antwerp; by M. G. A. Royers.

On the Inventions of James Watt, and his Models preserved at Handsworth and South Kensington; by Mr. Edward A. Cowper.

Report on Friction Experiments; by Mr. Beauchamp Tower.

First Report of the Committee on Friction at High Velocities: Professor Alexander B. W. Kennedy, Reporter.

The attendances at the Meetings have been as follows:—There were at the Annual General Meeting 82 Members and 67 Visitors; at the Spring Meeting 81 Members and 18 Visitors; at the Summer Meeting 152 Members and 33 Visitors; and at the Autumn Meeting 82 Members and 71 Visitors.

The Annual Summer Meeting was held this year in Belgium, partly in Liége and partly in Antwerp, and the Council feel sure that those who were present will agree with them in their opinion that nothing was left undone that could be done by our Belgian hosts to make the Meeting at once profitable and pleasurable. In this, in spite of unfavourable weather, they were thoroughly successful: the arrangements worked admirably, and the difficulties arising from different nationalities were no where felt. The Council feel sure that they will be anticipating the wish of the Members in making arrangements, as they have already begun to do, for the reception of the Belgian Engineers on a return visit, to be paid by them to England in the year 1885.

The Autumn Meeting for the past year, instead of being held as heretofore in Manchester, was transferred to Birmingham, with the intention, if the experiment was successful, of holding this Meeting in succession at the chief industrial centres, where the Institution possesses a considerable body of members. The Council are happy to state that this new departure promises well for the future, the attendance at Birmingham having been very good, and a marked interest having been shown in the Proceedings.

In accordance with the Rules of the Institution, the President, two Vice-Presidents, and five Members of Council in rotation, go out of office this day. The result of the ballot for the election of the Council for the present year will be reported to the Meeting.

COPY OF
ADDRESS OF CONDOLENCE TO LADY SIEMENS.

THE PRESIDENT AND COUNCIL

OF THE

INSTITUTION OF MECHANICAL ENGINEERS,

ON THE OCCASION OF THEIR
FIRST MEETING AFTER THE LAMENTED DEATH OF THE LATE

Sir William Siemens, D.C.L., F.R.S., &c.,

desire to express to Lady Siemens their sense of the loss therein sustained, not only by his relatives and friends, but by the nation and the world at large.

The leading part which he played in so many departments of science, both pure and applied, the valuable services he was continually rendering to the progress of the world, and the way in which he always upheld, by his personal example, the high character of his profession, render his place one which it will indeed be difficult to fill.

The Council have satisfaction in thinking that he always took a warm interest in the affairs of this Institution, with which his name will be associated, not only as one of its Past-Presidents, but also as a contributor of no less than thirteen papers to its Proceedings.

In these, some of his most brilliant inventions—such as the Chronometric Governor, the Water Meter, the Regenerative Gas Furnace, etc.—were first fully described; and they will always remain among the most valuable documents preserved in the records of the Institution.

The Council trust that, while they would not venture to obtrude any mere expression of condolence, they may be allowed thus to mark their sense of the great loss which this Institution has sustained, in common with science at large, by the death of their Past-President, Sir William Siemens.

Signed on behalf of the Council,

PERCY G. B. WESTMACOTT,

President.

APPENDIX I.

EXPENDITURE AND RECEIPTS.

BALANCE SHEET.

1883.

APPENDIX I.

Dr. ACCOUNT OF EXPENDITURE AND RECEIPTS

Expenditure.	£	s.	d.	£	s.	d.
To Printing and Engraving Proceedings of 1883 . . .	831	11	11			
Less Authors' Copies of Papers, repaid	125	4	0	706	7	11
,, Printing Library Catalogue and Index of Papers				37	6	1
,, Stationery, Binding, and General Printing				196	0	5
,, Rent				550	0	0
,, Salaries and Wages				1,541	13	0
,, Coals, Firewood, and Gas				23	18	0
,, Fittings and Repairs				120	19	4
,, Postages.				278	8	2
,, Insurance				2	13	9
,, Travelling Expenses				38	19	11
,, Petty Expenses				74	2	7
,, Meeting Expenses—						
Printing	188	5	3			
Reporting and Translating	70	13	3			
Diagrams, Screen, &c.	6	11	7			
Travelling and Incidental Expenses	158	0	1	423	10	2
,, Research				139	9	0
,, Books purchased				7	18	8
,, Drawings of Watt Models				55	5	3
Total Expenditure in 1883				4,196	12	3
Balance, being excess of Receipts over Expenditure, carried down .				493	9	2
				£4,690	1	5

	£	s.	d.
To amount invested in £891 Metropolitan Railway 4% Debenture Stock	999	13	10
Cash Balance at this date	727	16	10
	£1,727	10	8

APPENDIX I.

FOR THE YEAR ENDING 31ST DECEMBER 1883. *Cr.*

Receipts.	£ s. d.	£ s. d.
By Entrance Fees—		
81 *New Members at* £2	162 0 0	
5 *New Associates at* £2	10 0 0	
26 *New Graduates at* £1	26 0 0	
7 *Graduates transferred to Members at* £1	7 0 0	205 0 0
„ Subscriptions for 1883—		
1170 *Members at* £3	3,510 0 0	
28 *Associates at* £3	84 0 0	
92 *Graduates at* £2	184 0 0	
7 *Graduates transferred to Members at* £1	7 0 0	3,785 0 0
„ Subscriptions in arrear—		
45 *Members at* £3	135 0 0	
2 *Graduates at* £2	4 0 0	139 0 0
„ Subscriptions in advance—		
24 *Members at* £3	72 0 0	
1 *Graduate at* £2	2 0 0	74 0 0
„ Interest—		
From Investments	392 14 0	
From Bank	39 2 5	431 16 5
„ Reports of Proceedings—		
Extra Copies sold		55 5 0
		£4,690 1 5

By Balance brought down	493 9 2
Cash Balance 31st December 1882	1,234 1 6
	£1,727 10 8

Dr. BALANCE SHEET,

	£	s.	d.
Capital of the Institution at this date	15,050	15	3
	£15,050	15	3

(*Signed*) PERCY G. B. WESTMACOTT, *President.*

THOMAS R. CRAMPTON,
R. PRICE WILLIAMS, } *Finance Committee.*

AS AT 31ST DECEMBER 1883. *Cr.*

	£ s. d.	£ s. d.
By Cash—*In Bank, Deposit account*	200 0 0	
" " *Current* "	227 16 10	
In Secretary's hands	300 0 0	727 16 10
" Investments—		
£3,178 *London & N. W. Ry.* 4% *Debenture Stock*		
£2,200 *North Eastern* " " " "		
£2,466 *Midland* " " " "		
£1,800 *Great Western* " " " "		
£891 *Metropolitan* " " " "		
£10,535 . . . . *cost*		10,617 1 4
Note—The Market Value of these investments at 31st Dec. 1883 was about £ 12,000		
" Subscriptions in Arrear		286 0 0
" Office Furniture and Fittings		350 0 0
" Library and Proceedings		2,669 17 1
" Drawings, Engravings, Models, Specimens, and Sculpture .		400 0 0
		£15,050 15 3

Audited and Certified by

ROBERT A. McLEAN & Co., Chartered Accountants,

1 Queen Victoria Street, London, E.C.

APPENDIX II.

LIST OF DONATIONS TO LIBRARY.

Foundering of Steam-ships and how to prevent it, by Stephen H. Terry; from the author.

Engineers' Pocket-Book for 1883, by Adcock; from the proprietor.

Barometric Hypsometry, U. S. Coast Survey, by William Ferrel; from the U. S. Coast Survey.

Colliery Amalgamation, by W. T. and T. R. Mulvany; from the authors.

Elements of Machine Design, by W. Cawthorne Unwin; from the author.

Movements of Water in a Tidal River, by W. Cawthorne Unwin; from the author.

Treatise on Locomotive Engines, by Comte de Pambour; from Mr. J. R. Mosse.

Ventilation, by William Teague, Jun.; from the author.

Board of Trade Reports on Boiler Explosions; from the Board of Trade.

Recent Practice in Marine Engineering, by William H. Maw; from the author.

Official Report of the Smoke Abatement Committee, 1882; from Mr. D. K. Clark.

Cutting Tools worked by hand and machine, by Robert H. Smith; from the author.

Manual of Marine Engineering, by A. E. Seaton; from Messrs. Charles Griffin and Co.

Gas Reflecting Safety Lamp, by C. F. Lechien; from the author.

Life of Richard Trevithick, by Francis Trevithick; from Major John Davis.

Records of Royal Surrey Militia, by Major John Davis; from the author.

Observations on the River Tiber, by G. Bompiani; from the Minister of Public Works, Rome.

History of Petroleum, by Stéphane Goulichambaroff; from Mr. Thomas Urquhart.

Applied Mechanics, by Henry T. Bovey; from the author.

Reports of the U. S. Chief of Ordnance; from the Ordnance Office, Washington.

Catalogue of General Machinery; from Messrs. Bowes, Scott and Read.

Calendar of the Mason Science College, Birmingham; from the College.

Manual of Railway Engineering for the Field and the Office, by Charles P. Cotton; from the author.

Influence of the Board of Trade Rules for Boilers upon the Commercial Marine, by J. T. Milton; from the author.

Floods around Oxford, their causes, their effects, and the means of mitigating them, by L. F. Vernon-Harcourt; from the author.

The Student's Mechanics, an introduction to the study of Force and Motion, by Walter R. Browne; from the author.

Photographs of Watt Models in South Kensington Museum; from the Science and Art Department.

Lloyd's Register of British and Foreign Shipping, Rules and Regulations, 1882; from Mr. William Parker.

Brazil and her Railways, by Charles Waring; from the author.

Technological Dictionary, English French and German, by A. and L. Tolhausen; from the authors.

Report on a scheme for supplying Compressed-Air Motive Power in Birmingham, by Thomas Alfred English, Carl Julius Hanssen, John Sturgeon, and Henry Robinson; from Mr. John Sturgeon.

Instructions for the use and preservation of Portable Engines and Thrashing Machines, by Filippo Grimaldi; from Mr. Frank Garrett.

Saw Mills, their arrangement and management, and the economical conversion of Timber, by M. Powis Bale; from the author.

Comparative Trials made by M. A. Borodin in Russia of Compound and Ordinary Locomotives, by A. Mallet; from the author.

Handbook of House Property, by Edward Lance Tarbuck; from Messrs. Lockwood and Co.

Winding Engines with Automatic Expansion, by A. de Quillacq; from the author.

Mechanical Engineering of Collieries, by C. M. Percy; from the author.

Presidential Addresses to the North Staffordshire Institute of Mining and Mechanical Engineers, by John Brown; from the author.

Photograph from F. Breda's original Portrait of James Watt, 1793; from Mr. George B. Rennie.

Memoir of Ernest Marié, by M. E. Delerue; from M. Georges Marié.

Graphic Table for computing Weights of Wrought-Iron and Steel Girders, by J. H. Watson Buck; from Messrs. Lockwood and Co.

Notes on the Construction of Ordnance; from the Chief of Ordnance, Washington, U.S.

Report of the Brake Trial Board on the Woods and Westinghouse Continuous Automatic Railway Brakes; from the Agent General for Victoria.

On Fog Signalling, by Pablo Perez Seoane; from the author.

Catalogue of Steam Engines; from Messrs. J. Warner and Sons.

Explosions of Gas in Coal Bunkers, by Thomas Rowan; from the author.

Disease and Putrescent Air, by Thomas Rowan; from the author.

Compound Marine Engines for Short Passages, by J. Boulvin; from the author.

Modern Steam Practice and Engineering, by John G. Winton and W. J. Millar; from Messrs. Blackie & Son.

Official Catalogue of the Engineering and Metal Trades Exhibition; from the Secretary.

Calendar of University College, Bristol; from the College.

Improvements in Naval Engineering in Great Britain, by John A. Tobin; from the author.

Development of Mineral Resources of India, by A. N. Pearson; from the author.

Use of Steel Castings in lieu of Iron and Steel Forgings, by William Parker; from the author.

Equilibrium of Iron Piers, by L. Allievi; from the author.

Compound Engines for Agricultural purposes, by Messrs. Easton and Anderson; from Mr. William E. Rich.

Regulations relating to the Examinations of Engineers for the Board of Trade; from Mr. J. McFarlane Gray.

Catalogue of Chinese Collection of Exhibits at the International Fisheries Exhibition; from the Inspector-General, Chinese Customs Office.

Supply of Electricity by local authorities, by Killingworth W. Hedges; from the author.

Catalogue of the International Electric Exhibition at Vienna, 1883; from the Directors.

Experiments with the Extension Indicator, by Dr. W. Fränkel; from the author.

Utilisation of the Motive Power of the Rhone; from M. A. Achard.

Summary of the new Patent Act, 1883, by W. Lloyd Wise; from the author.

Action of Brakes, by M. Seguela; from the author.

Treatise on Cranes, by Henry R. Towne; from the author.

Inaugural Address to the University of Liége, by L. Trasenster; from the author.

Transmission of Power by Belts, Cords, and Wire-Ropes, by G. Leloutre; from the North of France Industrial Society.

High Masonry Dams, by Guilford L. Molesworth; from the author.

Text-book on Workshop Appliances, by C. P. B. Shelley; from the author.

Report on the description of Creasote best suited for Creasoting Timber, by Dr. C. M. Tidy; from the Gas Light and Coke Co.

Safe Working of Railways, by F. Loewe; from the author.

Illustrated Catalogue of Wood-working Machinery; from Messrs. F. W. Reynolds & Co.

Whitworth Scholarships and how to obtain them, by Thomas Turner; from the author.

Coach Building; from the Newcastle-on-Tyne Public Library.

Resistance and Proportions of Screw-Propellers, by W. Bury; from the author.

Report of the Kew Committee for 1883; from the Committee.

Grosvenor Gallery Library Catalogues; from the Library.

Reports of the Academy of Sciences, France; from the Academy.

Reports of the Royal Academy of Sciences, Belgium; from the Academy.

Reports of the Royal Institute of Engineers, Holland; from the Institute.

École des Ponts et Chaussées, Paris, Engravings; from the School.

Annales des Ponts et Chaussées, Paris; from the Directors.

Proceedings of the French Institution of Civil Engineers; from the Institution.
Journal of the French Society for the Encouragement of National Industry; from the Society.
Report of the French Association for the Advancement of Science; from the Association.
Journal of the Marseilles Scientific and Industrial Society; from the Society.
Proceedings of the Engineers' and Architects' Society of Milan; from the Society.
Proceedings of the Engineers' and Architects' Society of Rome; from the Society.
Proceedings of the Engineers' and Architects' Society of Florence; from the Society.
Proceedings of the Engineers' and Architects' Society of Canton Vaud; from the Society.
Proceedings of the Engineers' and Architects' Society of Austria; from the Society.
Proceedings of the Architects' and Engineers' Society of Hanover; from the Society.
Proceedings of the Engineers' and Architects' Society of Prague; from the Society.
Proceedings of the Industrial Society of St. Quentin; from the Society.
Proceedings of the Industrial Society of Mulhouse; from the Society.
Proceedings of the Industrial Society of the North of France; from the Society.
Proceedings of the Saxon Society of Engineers and Architects; from the Society.
Proceedings of the Swedish Society of Engineers; from the Society.
Journal of the Norwegian Polytechnic Society; from the Society.
Journal of the Belgian State Railways; from the Railway Committee.
Journal of the Franklin Institute; from the Institute.
Transactions of the American Society of Civil Engineers; from the Society.
Transactions of the American Institute of Mining Engineers; from the Institute.
Report of the Smithsonian Institution; from the Institution.
Proceedings of the United States Naval Institute; from the Institute.
Proceedings of the American Meteorological Society; from the Society.
United States Patent Office Gazette; from the Office.
Professional Papers on Indian Engineering; from the Thomason College.
Proceedings and Journal of the Asiatic Society of Bengal; from the Society
Report of the Sassoon Mechanics' Institute, Bombay; from the Institute.
Proceedings of the Institution of Civil Engineers; from the Institution.
Journal of the Iron and Steel Institute; from the Institute.
Transactions of the Society of Engineers; from the Society.
Journal of the Society of Telegraph Engineers; from the Society.
Transactions of the Institution of Civil Engineers of Ireland; from the Institution.
Transactions of the North of England Institute of Mining and Mechanical Engineers; from the Institute.

Proceedings of the South Wales Institute of Engineers; from the Institute.

Transactions of the Institution of Engineers and Shipbuilders in Scotland; from the Institution.

Proceedings of the Chesterfield and Derbyshire Institute of Mining, Civil, and Mechanical Engineers; from the Institute.

Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers; from the Institute.

Proceedings of the Cleveland Institution of Engineers; from the Institution.

Transactions of the West of Scotland Mining Institute; from the Institute.

Proceedings of the Royal Society of London; from the Society.

Proceedings of the Royal Society of Edinburgh; from the Society.

Proceedings of the Royal Institution; from the Institution.

Transactions of the Institution of Surveyors; from the Institution.

Proceedings of the Association of Municipal and Sanitary Engineers and Surveyors; from the Association.

Journal of the Royal United Service Institution; from the Institution.

Papers of the Royal Engineer Institute; from the Institute.

Proceedings of the Royal Artillery Institution; from the Institution.

Journal of the Royal Agricultural Society of England; from the Society.

Journal of the Statistical Society; from the Society.

Report of the British Association for the Advancement of Science; from the Association.

Report of the Royal Cornwall Polytechnic Society; from the Society.

Report of the Miners' Association of Cornwall and Devon; from the Association.

Transactions of the Institution of Naval Architects; from the Institution.

Transactions of the Royal Institute of British Architects; from the Institute.

Report of the British Association of Gas Managers; from the Association.

Proceedings of the Physical Society of London; from the Society.

Proceedings of the Literary and Philosophical Society of Manchester; from the Society.

Report of the Manchester Geological Society; from the Society.

Journal of the Royal Scottish Society of Arts; from the Society.

Proceedings of the Philosophical Society of Glasgow; from the Society.

Transactions and Proceedings of the Royal Irish Academy; from the Academy.

Transactions of the Liverpool Engineering Society; from the Society.

Journal of the Liverpool Polytechnic Society; from the Society.

Proceedings of the Birmingham Philosophical Society; from the Society.

Journal of the Society of Arts; from the Society.

Reports of the Manchester Steam Users' Association; from Mr. Lavington E. Fletcher.

Report of the Boiler Insurance and Steam Power Company; from Mr. Niel McDougall.

Report of the National Boiler Insurance Company; from Mr. Henry Hiller.
Report of the Engine, Boiler, and Employers' Liability Insurance Company; from Mr. Michael Longridge.
Catalogue of the Liverpool Free Public Library; from the Committee.

The Engineer; from the Editor.
Engineering; from the Editor.
Iron; from the Editor.
The Mining Journal; from the Editor.
The Railway Record; from the Editor.
The Colliery Guardian; from the Editor.
The Iron and Coal Trades Review; from the Editor.
Ryland's Iron Trade Circular; from the Editor.
Revue générale des Chemins de fer; from the Directors.
Der Civilingenieur; from the Editor.
The Railroad Gazette; from the Editor.
The Railway Engineer; from the Editor.
The Engineering and Mining Journal; from the Editor.
The Telegraphic Journal and Electrical Review; from the Editor.
The Fireman; from the Editor.
The Marine Engineer; from the Editor.
The Contract Journal; from the Editor.

The PRESIDENT, referring to the list of deceases presented in the Report of the Council, said the Institution had to lament the loss of their deeply respected Past-President, Sir William Siemens; and he laid before the meeting, for inspection by the Members, the engrossed address of condolence which had been prepared for presentation to Lady Siemens.

After commenting upon various matters connected with the statement of accounts, and upon other points in the Report, he announced that a hearty invitation had been received from their friends in South Wales to hold this year's Summer Meeting in Cardiff; and he was quite sure that those Members who recollected their excellent Meeting held there ten years ago, as well as all who had joined the Institution since that time, would look forward to this year's Meeting there with great pleasure and interest.

He now moved the adoption of the Annual Report of the Council.

The motion was seconded by Mr. EDWARD A. COWPER.

Mr. DANIEL ADAMSON proposed the following resolution:—"That in the opinion of this meeting, as the Secretary sent in his resignation, which was in due course accepted by the Council to take effect on 19th January 1884 (such notice being given on 19th July 1883), and this was recorded in the minutes of the Council, Mr. Browne therefore is not now the Secretary of the Institution. In accordance with Bye-Law 20 the election of a Secretary now rests with the Members; and therefore any proposals which Mr. Browne may wish to make should be stated in writing when he offers himself as a candidate to be elected as Secretary by the Members of the Institution." In support of this view he had obtained counsel's opinion, which he handed to the President for the consideration of the Council.

The PRESIDENT stated the Council had been advised by the Honorary Solicitor that so long as the Secretary was in office they were legally entitled to re-appoint him.

Mr. W. LLOYD WISE seconded the resolution. After discussion, it was ultimately withdrawn in favour of the following amendment.

Mr. E. HAMER CARBUTT, M.P., moved as an amendment:—"That the part of the Report referring to the alterations in the staff

of the Institution be referred back to the Council for re-consideration, with instructions to them to try to retain the valued assistance of Mr. Bache, and not to diminish either the number or the efficiency of the staff."

The amendment was seconded by Mr. R. PRICE WILLIAMS.

Mr. WILLIAM BOYD moved as a further amendment that the instructions included in the preceding amendment be omitted therefrom. This further amendment having been seconded by Mr. PETER D. BENNETT was put to the Meeting, and was negatived.

The amendment moved by Mr. Carbutt was then put, and was carried.

The PRESIDENT moved the adoption of the Annual Report of the Council, subject to the amendment which had been passed. This motion having been seconded by Mr. I. LOWTHIAN BELL, F.R.S., was put to the Meeting, and was carried.

The PRESIDENT announced that the Ballot Lists for the election of Officers had been opened by a committee of the Council, and the following were found to be elected for the present year:—

PRESIDENT.

I. LOWTHIAN BELL, F.R.S.,
Rounton Grange, Northallerton.

VICE-PRESIDENTS.

CHARLES COCHRANE, ...	Stourbridge.
RICHARD PEACOCK, ...	Manchester.
FRANCIS W. WEBB, ...	Crewe.

MEMBERS OF COUNCIL.

WILLIAM BOYD, ...	Newcastle-on-Tyne.
DAVID GREIG, ...	Leeds.
SAMUEL W. JOHNSON, ...	Derby.
ARTHUR PAGET, ...	Loughborough.
SIR JAMES RAMSDEN, ...	Barrow-in-Furness.

The Council for the present year would therefore be as follows :—

PRESIDENT.

I. LOWTHIAN BELL, F.R.S.,
Rounton Grange, Northallerton.

PAST-PRESIDENTS.

SIR WILLIAM G. ARMSTRONG, C.B., D.C.L., LL.D., F.R.S.,	Newcastle-on-Tyne.
SIR FREDERICK J. BRAMWELL, F.R.S.,	London.
EDWARD A. COWPER,	London.
THOMAS HAWKSLEY, F.R.S.,	London.
JAMES KENNEDY,	Liverpool.
JOHN RAMSBOTTOM,	Alderley Edge.
JOHN ROBINSON,	Manchester.
PERCY G. B. WESTMACOTT,	Newcastle-on-Tyne.
SIR JOSEPH WHITWORTH, BART., D.C.L., LL.D., F.R.S.,	Manchester.

VICE-PRESIDENTS.

CHARLES COCHRANE,	Stourbridge.
THOMAS R. CRAMPTON,	London.
JEREMIAH HEAD,	Middlesbrough.
RICHARD PEACOCK,	Manchester.
GEORGE B. RENNIE,	London.
FRANCIS W. WEBB,	Crewe.

MEMBERS OF COUNCIL.

DANIEL ADAMSON,	Manchester.
WILLIAM ANDERSON,	London.
WILLIAM BOYD,	Newcastle-on-Tyne.
DAVID GREIG,	Leeds.
SAMUEL W. JOHNSON,	Derby.
J. HAWTHORN KITSON,	Leeds.
FRANCIS C. MARSHALL,	Newcastle-on-Tyne.
ARTHUR PAGET,	Loughborough.
SIR JAMES RAMSDEN,	Barrow-in-Furness.
E. WINDSOR RICHARDS,	Middlesbrough.

William Richardson, ...	Oldham.
Bernhard Samuelson, M.P., F.R.S., .	London.
Joseph Tomlinson, Jun., ...	London.
Ralph H. Tweddell, ...	London.
R. Price Williams, ...	London.

The President said the time had now come for him to give back the trust which had been reposed in him two years ago. When the members did him the honour to elect him as their President, when in fact they put a stamp on his professional life of which he should always feel proud, he made the simple promise, feeling that he had not power to do more, that he would attend assiduously to the duties of his high office, and do his best to uphold the dignity of the chair. He was quite sensible of his own deficiencies; but he could conscientiously say that he had fulfilled his promise to the very best of his ability and powers. He was glad to think that the Institution had made substantial progress during the last two years. He wished to take that opportunity of expressing his sense of the very great kindness, assistance, and goodwill that had been shown to him by the members of the Council, one and all; and also to express his obligations to the members of the staff, especially to their able Secretary, Mr. Browne. He begged again to express his sincere thanks for the attention with which the members had always listened to him, and for the forbearance shown to him during the whole of the time of his presidency. Before vacating the chair, he desired to express the extreme gratification it was to him to know that he should be succeeded by so able and experienced a gentleman as his friend, Mr. Bell.

The chair was then taken by Mr. I. Lowthian Bell, F.R.S., President elect.

Mr. Bell said at that late hour he would not detain the members with any lengthened expression of his thanks for the very great honour which his colleagues on the Council had conferred upon him, and which the members had so kindly ratified. The position of

President of a great Institution like that of the Mechanical Engineers was of course one of those marks of professional and social distinction of which any one who had devoted his life to the furtherance of technical science and technical progress might well be proud. At the same time he must confess that he was rather astounded at his own temerity in having, after some pressing from his friend Mr. Westmacott, signified a willingness to receive upon his unworthy shoulders a mantle which had fallen from those of men so much better qualified than he could pretend to be to wear it. But of one thing they might be assured—that the same sentiments that had been expressed by the retiring President, as being those which had actuated him on taking office, would remain steadily before himself while he endeavoured to discharge the functions of his high position. In conclusion he begged to thank the members most sincerely for the distinguished honour they had conferred upon him by electing him as their President.

Mr. T. HAWKSLEY said it had fallen to his lot—a very agreeable one—to have the pleasure, as the oldest of the Past-Presidents of the Institution, to propose a vote of thanks to the gentleman who had just retired from the chair. He was perfectly assured that the members fully appreciated the manner in which during the last two years the business of the Institution had been conducted by him—always with urbanity, always with kindness, always with intelligence, and always, whenever questions had come up which were difficult of solution in the discussions, with eminent scientific knowledge. He had so conducted the affairs of the Institution as to prove that he himself had been most anxious to promote its best interests. He hoped the meeting would receive with acclamation the proposition he was about to make:—that the cordial thanks of the members be given to their Past-President, Mr. Westmacott, for the excellent manner in which he had conducted the affairs of the Institution during the two years in which he had reigned over them.

The vote of thanks was carried by acclamation.

Mr. WESTMACOTT returned his most sincere thanks.

The Meeting was at Ten o'clock adjourned till the following evening.

The ADJOURNED MEETING of the Institution was held at the Institution of Civil Engineers, London, on Friday, 25th January 1884, at Half-past Seven o'clock p.m.: CHARLES COCHRANE, Esq., Vice-President, in the chair, in the absence of the President through indisposition.

Mr. WALTER R. BROWNE, in announcing to the Members his resignation of the post of Secretary, said he spoke from a position which for the last six years he had not occupied there—that of a Member of the Institution. He asked the Members kindly to give him a courteous hearing, and he promised not to detain them long. At the meeting yesterday an opinion had been expressed, and counsel's opinion had been quoted in support of it, that the Council had unwittingly acted in excess of their legal powers in accepting the withdrawal of his resignation, which he had been induced to offer last autumn. That was a question on which gentlemen learned in the law might differ, and did differ; but it was no wish of his to raise such a question at all. So far as his personal wishes were concerned, he desired it to be understood that his connection with the Institution as Secretary ceased from the present time. He simply left it in the hands of the Council as to whether they would wish him to continue as interim Secretary for a few days until his successor was appointed, or as to whatever else they might determine. He wished also to state emphatically that never at any time, either when he was engaged as Secretary or since, had there been an understanding, or a hint or a shadow of an understanding, that when he had done the work of the Institution his time was not his own to do with it as he pleased. He had been engaged to do the work of the Institution, and that work he had done; and he was not afraid to challenge a comparison as to the way in which that work had been done with that of any other Institution. Might he say one word more? When

he handed in his resignation to the Council last spring, it was without assigning any motives, and it was only when very great pressure was put upon him from very many quarters that he reluctantly, and against his better judgment, consented to re-open the question. He therefore hoped that members in fairness would admit that, to whomsoever the present interruption to the general harmony of their proceedings was due, it was at least not due to him. But he did not wish that these, the last words that he should speak, on any personal matter at least, should be words of bitterness or of complaint. To all those who during the six years he had held office had tried to make that office a pleasant one,—to very many members of Council, and pre-eminently to the present President Mr. Bell, and the late President Mr. Westmacott,—to all the authors of the papers which had been read during that time, with whom his relations had always been of the most cordial and friendly character,—and lastly to the Members in general,—he desired to offer his sincere and lasting thanks.

The Minutes of the last Meeting, containing the correction which had been ordered to be made, were approved as correct, and were signed by the Chairman.

The CHAIRMAN moved the following resolution, in pursuance of notice given at the last meeting:—

That Bye-Law No. 21 shall hereafter read as follows:—" It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all meetings of the Institution, and of the Council, and of Committees; to take minutes of the proceedings of such meetings; to read the minutes of the preceding meetings, and all communications that he may be ordered to read; to superintend the publication of such papers as the Council may direct; to have the charge of the library; to direct the collection of the subscriptions, and the preparation of the account of expenditure of the funds; and to present all accounts to the Council for inspection and approval. He shall also engage (subject to the approval of the Council) and be

responsible for all persons employed under him, and set them their portions of work and duties. He shall conduct the ordinary business of the Institution in accordance with the Articles and Bye-Laws and the directions of the President and Council; and shall refer to the President in any matters of difficulty or importance, requiring immediate decision."

Mr. HENRY CHAPMAN seconded the motion, and it was carried.

Mr. ARTHUR PAGET moved, in accordance with notice given at the last meeting:—

That words to the following effect shall be added to Bye-Law 20:—"The Secretary shall devote the whole of his time to the work of the Institution, and shall not engage in any other business or profession."

Mr. PETER D. BENNETT seconded the motion. In doing so he also suggested that the Council should be looking out for a house for the Institution, having now about £12,000 invested.

The motion, after having been supported by other Members, was put to the Meeting, and carried unanimously.

The discussion adjourned from the last Meeting, upon Experiments on Friction, was resumed and concluded.

The following paper was then read and discussed:—

On the Physical Conditions of Iron and Steel; by Professor D. E. Hughes, F.R.S.

The CHAIRMAN moved a hearty vote of thanks to the Institution of Civil Engineers for their kindness in granting the use of their rooms for the Meeting of the Institution. The Members were all

aware of the great advantage they thus enjoyed, which indeed was almost a sufficient inducement to them to reject the suggestion of having a house of their own, so long as they were granted such an excellent place to come to as that in which they were now assembled. Still Mr. Bennett's suggestion might prove a valuable one at some future time when they had more funds.

The vote of thanks was carried by acclamation.

The Meeting then terminated.

FIRST REPORT ON FRICTION EXPERIMENTS.

By MR. BEAUCHAMP TOWER, OF LONDON.

Adjourned Discussion.

(*Continued from Proceedings November* 1883, *p.* 659.)

Mr. TOWER, referring to Mr. Wicksteed's statement about the very high pressures put upon the eccentric pins of punching and shearing machines, observed that, in addition to the alternation in its direction, the pressure was applied for only a very short space of time in these machines: so that the oil had not time to be squeezed out. Probably an infinite pressure might be applied for an infinitely short time without seizing.

In regard to Mr. Robinson's remark about the difficulty of applying the oil-bath in practice, all that was necessary to produce results as good as those of the oil-bath was that the journal should be wetted with as much oil as would hang on to it; this was shown by the fact that, if the bottom of the journal only just touched the oil, this was sufficient to give as good results as if the oil-bath were full. Equally good lubrication would probably be given by a roller floating in a reservoir of oil under the bearing, and turning round with its upper surface touching the under surface of the journal.* Mr. William Anderson had told him that this appliance had been used in his own experience, but had been given up, probably because people did not know its real value. The most important practical lesson to be learnt from these experiments was, in his opinion, the value of profuse lubrication, and the great diminution of friction to be obtained thereby. The oil-bath friction was only one-sixth or one-seventh of the friction when lubricating on the ordinary system of a drop at a time. It was quite possible to have profuse lubrication,

* See Proceedings 1853, p. 60, and Plate 11, Fig. 2.

and yet waste very little oil; all that was necessary was to take care that all the oil dropping from the bearing was caught and returned to it by means of a pump or a roller or in any other way; but it should be poured over the bearing in profusion, and not dribbled on by drops. None of these suggestions were new; but he considered the reason why this profuse lubrication had not been used in practice for important bearings, such as the crank-shaft bearings of large marine engines, was that the great advantage to be derived from it, to which these experiments pointed conclusively, was not known. No doubt a practical recognition of the value of profuse lubrication was seen in the trial trips of large marine engines, especially when there was a premium for extra horse-power; but in those cases the oil generally ran straight from the bearings into the bilge, and was wasted. The present experiments showed that the rate of lubrication adopted in such trial trips should be kept up at all times, though the wastefulness need not accompany it.

With regard to the high pressure often put on crank-pins, as referred to by Mr. Davey and Mr. Halpin, the illustration given by the latter as to the difference usual in the practical treatment of bearings on which the pressure alternated in direction, and of those on which it was constant both in direction and intensity, was probably the best that could be given: indeed he was told the difference was still greater than Mr. Halpin had put it. He understood Mr. Tomlinson had found in practice that it was undesirable to put more than about 300 lbs. per sq. inch on locomotive axle-boxes, whereas on crank-pins the pressure was often considerably over 1000 lbs. per sq. inch. There was one important alleviation to this extreme pressure on crank-pins when running at high speeds, which had been referred to by Mr. Halpin as the modifying effect due to the weight of the reciprocating parts: that is, a part of the pressure at the beginning of the stroke, when the pressure was highest, was absorbed in overcoming the inertia of the piston and piston-rod and connecting-rod. In this way the extreme pressure on the crank-pin of a locomotive going about 40 miles an hour was diminished about one-fourth or one-third, as he had made out: so that these high pressures must be considerably diminished at high speeds.

With regard to the lathe mandril mentioned by Mr. Lea, he could not understand the phenomenon described, unless it were that the metal of the headstock was sprung into proper form by the screwing down of the cap. It was easy to imagine this might be the case, as the bearing was probably bored out originally with the cap tightly screwed down, and might only be of the true bored-out form under that condition; the removal of the cap might allow the bearing to spring back into an untrue shape.

In answer to Professor Smith's question about the arrangement of the bearing which had been experimented on, the journal was not an overhanging one, but was supported on both sides by bearings which were as close to the experimental journal as possible. That the bearings did not suffer any detriment from the slight distortion caused by the experimental journal not being supported immediately under the load, was inferred with certainty from the beautiful surface which both the brass and the journal acquired, and from the perfect oil-tight fit which they became; whatever slight distortion there was, the brass and cap doubtless adapted themselves easily to it by their own elasticity. With regard to the steadiness of the pointer and suspended weight, very great difficulty from the oscillation of the suspended weight had been anticipated before the experiments were begun, and preparations had been made for using a large and powerful dashpot to check the oscillations; but when the machine was started, it was found that these fears had been altogether groundless, the weight remaining perfectly steady and the dashpot being unnecessary. The explanation of the absence of a tendency to oscillate was found in the fact that the experiments had been tried at speeds so high as to give an increase of friction with an increase of speed; at low speeds, when the friction diminished with an increase of speed, there was a tendency for a hanging weight, like that used in these experiments, to oscillate, and for the oscillations to keep on increasing in amplitude. In the oil-bath experiments the coefficient remained very steady, because the temperature was kept constant, the lubrication constant, and in fact everything constant, except the variable which was being observed; but in the experiments on ordinary lubrication the difficulties were met with which had been

mentioned on page 641. The pointer did not oscillate in the sense of getting up a periodic swing; but it kept on varying in position, indicating a varying friction, so that it was impossible to know what to record. It was the correct anticipation of these irregularities in ordinary lubrication that had led to the proposal of the oil-bath as the only way in which a perfectly constant rate of lubrication could be ensured; and he had no doubt that the oil-bath experiments could be reproduced at any time with the same results, but the experiments with common lubrication might be tried over again for a long time before exactly the same results as previously could be got from them. The oil-bath results were a definite measure of a definite thing; and they were more congruous with one another, he believed, and consequently threw a greater light on the true theory of the matter, than any previous experiments.

These experiments he believed had been projected in consequence of those made by Professor Thurston, to which they were intended to be supplementary, in order to clear up some points that had been left untouched by him. So far as he was aware, these experiments were the first which had been tried with a constant temperature. The diminution of absolute friction with an increase of load, referred to by Professor Smith as observed by Professor Thurston, was due he believed to an increase of temperature, and a consequent increase of fluidity of the oil; and it would certainly have been experienced in the present trials, had the temperature been allowed to take care of itself. In Professor Thurston's experiments the temperatures had frequently been observed; but it did not seem he had ever attempted to control them or keep them constant. Many of Professor Thurston's experiments had been at low speeds, whereas all the present ones had been at high speeds.

With regard to the meaning of the loads stated in the tables, the nominal load there given per square inch was the total load divided by the product of the diameter and the length of the journal; for the actual load the divisor would be the product of the chord of the arc of contact of the brass, multiplied by the length of the brass; and of course when the brass embraced half the journal these two quantities would be the same. He should be very much interested to hear the

results obtained by Professor Smith with his new experimental apparatus at the Mason Science College for testing journal-friction with different oils.

With regard to Mr. Price Williams' question about the grooving of the brasses, the method of grooving which had been tried in these experiments, and had been described in the Report as that found to answer in railway vehicles, was the method used on the Metropolitan Railway by Mr. Tomlinson, and found to answer; that is to say, it was found to work on that line without heating or giving trouble.

Mr. J. C. FELL, as one of the members of the Committee on Friction, thought it was very important that no false conclusions should be drawn from the Report on the experiments which had been made. There was one great peculiarity in all these experiments, which no doubt would be further dealt with, as the experiments were proposed to be continued: namely, that the load upon the experimental bearing was on the same face as that on which the lubrication was applied, when the testing was made to compare the ordinary method of lubrication with the more novel methods adopted in these experiments. That would be particularly the case with the bearings of all rolling stock, where the load was always on the top brass through which the lubrication was applied. But there were an immense number of ordinary bearings—shafting and crank-shaft bearings, and so on—in which the load was not necessarily applied on the surface through which the ordinary lubrication was admitted; and he thought it might be open to question how far the very imperfect or bad results from a frictional point of view, that were obtained by the tests upon the methods of ordinary lubrication, might be varied by the load being upon the face opposite to that through which the lubricant was supplied. That was one point in regard to which a reservation might be made until the question was more thoroughly cleared up.

Another point that might gravely affect the character of the result was the possible end-play of the bearings; and he believed it was intended further to investigate this point, which had been raised by another member of the Committee, and was no doubt an important

one. The bearings that had been experimented upon were fitted comparatively tight. In nine out of ten ordinary bearings there was a considerable amount of end-play; and how far this might affect the diffusion of the lubricant might be considered an open question.

He would supplement his remarks by suggesting whether the results arrived at in these and other experimental researches might not be embodied in some kind of diagramatic representation. If that plan were adopted, it seemed to him that it would convey a clearer and more lasting impression than was derived from any mere tabulation of figures.

Mr. W. E. RICH, referring to the remarks made by Mr. Tower with regard to high-speed bearings, said that some very efficient examples of high-speed bearings lubricated from beneath, which he had known for several years past, were those used by Mr. Allen Ransome for the revolving journals of his wood-working machines, some of which worked up to 3000 and 4000 revolutions per minute. The bearing had a long open slot on its under side, and a reservoir of clean oil beneath; and a pad of felt touching the under side of the journal carried up the oil by capillary attraction. The only weak point in that plan, he understood from Mr. Ransome, was the hardening of the surface of the felt by the constant rubbing of the highly polished spindle upon it, whereby the free passage of oil through it was impeded.

Mr. TOWER said it was of course impossible to try every form of bearing that was used in every individual case. They could only try some typical form, such as would deal in a scientific way with the questions of the friction, the lubrication, and the various other conditions. For instance in the bearings of railway axles there was a continual end-play; and no doubt, as stated in the Report, this considerably modified the action of the lubricant. With the experimental bearing it had been found that the oil could not get down into the bearing when put in at the top, because the journal fitted the brass so accurately. But the fact that, under practical conditions, as in the case of railway journals, the oil did go down,

was no doubt because the journal and the brass were not so beautifully fitted and that there was an end-play in the brass. Still, it was utterly impossible to try every form which bearings and brasses took in mechanical engineering; they could only try one form which might be regarded as typical.

With reference to Mr. Rich's observation about Mr. Ransome's journal, that method of lubricating the bearing underneath by an oil reservoir and pad was very similar to the method which had been employed in these experiments, and he believed it was the best method of lubrication. One marked result of the experiments was to show that the worst possible place for trying to introduce a lubricant into a bearing was in the middle of the seat of pressure. The journal ought to be oiled at some part where there was no pressure, trusting to the adhesion of the oil to the journal for carrying it to the place where there was pressure. If the oil was applied in the middle of the seat of pressure, it would be squeezed out and escape just where it was most wanted to counteract the pressure.

The CHAIRMAN was sure the members would agree with him in returning their hearty thanks to Mr. Tower, not only for the pains he had taken in drawing up the Report that had been read at the previous meeting, but also for the observations he had made on the present occasion.

ON THE PHYSICAL CONDITION OF IRON AND STEEL.

BY PROFESSOR D. E. HUGHES, F.R.S.

In a paper read before the Royal Society, 5th May 1879, entitled "On an Induction Currents Balance, and experimental researches made therewith," the author showed that this instrument was extremely sensitive to all molecular changes in metallic bodies. Finding that its powers were remarkably suitable for researches upon the molecular change which takes place in Iron and Steel when tempered, he made with it a series of researches to determine the cause of tempering in steel. The results of these he laid before the Institution of Mechanical Engineers (Proceedings 1883, p. 72) in a paper "On the Molecular Rigidity of Tempered Steel." In that paper he advanced the theory that the molecules of soft iron were comparatively free as regards motion amongst themselves, whilst in hard iron or steel they were extremely rigid in their relative positions.

The author has since widened the field of research so as to embrace all the physical changes which occur in iron and steel through chemical alloys, mechanical compression or other strains, annealing, and tempering. The results of these researches he now embodies in the present paper. Believing it necessary that we should be able to tell the physical state of any piece of iron, without destroying or changing that state, he has sought for and tried several methods which gave any hope of success in this direction. The physical state of iron has a marked influence upon its electric conductivity. The differences thus indicated however are not wide enough to be appreciated except with metal in the form of wire; and in order to perceive small changes, such as small differences of temper, we should require a wire at least 250 yards in length. The author has found however that by the application of certain

phenomena belonging to magnetism we are enabled to perceive clearly the slightest change in the molecular structure of iron or steel, through all degrees of annealing to the finest differences in tempering, and this with pieces of any form or dimensions.

It is already known that soft iron will take a higher degree of magnetism, and retain it less, than steel; and that tempered steel retains magnetism more than soft steel. Consequently we might expect that, by the aid of an instrument which could give correct measurement of degrees of magnetism, we should be able to include all varieties of iron and steel, between the two extremes of softness as in annealed iron, and hardness as in highly tempered cast-steel. The author soon found that this was not the case when pieces of iron were magnetised to saturation, or even partially so.

In a recent paper upon the theory of magnetism* the author said, "During these researches I have remarked a peculiar property of magnetism, viz., that not only can the molecules of iron or steel be rotated through any degree of arc to its maximum or saturation, but that each molecule, whilst it requires a comparatively strong force to overcome its rigidity or resistance to rotation, has a small field of its own through which it can move with excessive freedom, trembling, vibrating, or rotating through small arcs with infinitely less force than would be required to rotate it permanently on either side. This property is so marked and general that we can observe it without any special iron or apparatus."

The author has found, by employing extremely feeble magnetising powers,—such as a weak current of electricity only just sufficient for measurement, or the current from one Daniell cell reduced (as found best for the dimensions of the iron) by passing it through resistance-coils varying from 10 to 100 ohms,—that the following laws hold with every variety of iron and steel :—

1. The magnetic capacity is directly proportional to the softness, or molecular freedom.

2. The resistance to a feeble external magnetising force is directly as the hardness, or molecular rigidity.

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* Society of Telegraph Engineers, 24th May 1883.

The author has proved this to be the case with sixty different varieties of iron and steel furnished direct from the manufacturers. And he has found that each variety of iron or steel has fixed points, beyond which annealing cannot soften, nor tempering harden; consequently, if all varieties were equally and perfectly annealed, each variety would have its own magnetic capacity, or its specific degree of value, by means of which we could at once determine its place and quality.

If in place of several varieties we take a single specimen, say hard-drawn Swedish iron wire, and note its magnetic capacity, we find that its value rises rapidly with each partial annealing, until an ultimate softness is obtained, being the limit of its molecular freedom. We are thus enabled to study the best methods of annealing, and to find at once the degree of softness in an unknown specimen.

Similarly, when we temper annealed iron and steel, we find that we can follow out each degree of temper up to ultimate molecular rigidity; and we may thus appreciate, in an unknown specimen of unknown temper, the degree of its hardness.

We have thus in each piece of iron or steel a limit of softness and hardness. In soft Swedish iron, tempering hardens it but 25 per cent. on the scale adopted; whilst mechanical compression, such as hammering, hardens it 50 per cent. In cast steel, tempering hardens it 400 per cent., whilst mechanical compression gives but 50 per cent. Between cast steel and Swedish iron, we find a long series of mild steel, hard iron, &c., varying in their proportionate degrees between the two extremes just mentioned.

The theory which the author has advanced, of molecular freedom as in soft iron, and molecular rigidity as in cast steel, fully explains all the changes which we are enabled to perceive and measure; but it is not absolutely necessary to accept the theory, in order to appreciate the results. For, leaving theoretical considerations aside, we have one proved fact: namely that the magnetic power or capacity of a piece of iron, under the influence of an external limited magnetising power, depends upon its softness; and that the retention of magnetism, when the external power is withdrawn, depends upon its hardness. The same degree of temper or annealing, upon the same iron or

steel, gives invariably the same readings; but the slightest change—say from a straw-coloured temper to a blue—gives very wide differences.

Description of Apparatus.

The instrument which the author has constructed and used in these experiments, and which he has named a "Magnetic Balance," consists of a delicate magnetic needle N, Fig. 1, Plate 1, suspended by a silk fibre; it is 5 centimetres in length (2 ins.), and its pointer rests near an index having a single fine black mark for its zero. The movement of the needle on either side of zero is limited to 5 millimetres (0·2 in.) by means of ivory stops or projections. When the north end of the needle and its zero index are north, the needle rests parallel with its index; but the slightest external influence, such as a piece of iron 1 millimetre in diameter (0·04 in.) placed at 10 centimetres distance (4 ins.), deflects the needle to the right or left, according to the polarity of its magnetism, and with a force proportionate to its magnetic power. If we place on the opposite side of the needle, and at the same distance, a wire possessing absolutely the same polarity, of similar name and force, the two balance each other and the needle returns to zero; and if we know the magnetic value required to balance the first piece of iron we know the magnetic value of both.

The iron I, which may be in the form of wires, rods, bars, plates, or any shape or size desired,* is placed at a fixed distance, preferably 10 or more centimetres (4 ins.), resting against a fixed brass stop C. The centre line of the iron should be in line with the centre on which the needle turns, and it should be placed at right angles to the needle, lying horizontally east and west, so as to be free from the directing influence of the earth's magnetism.

The compensator, placed upon the opposite side of the needle, and at a distance of 30 centimetres (12 ins.), consists of a powerful steel bar-magnet, 3 centimetres wide, 1 centimetre thick, and 15 centimetres long ($1·18 \times 0·4 \times 5·91$ ins.). This turns upon

* The smallest rods yet tested have been fine sewing needles; and the largest, bars of 5 centimetres (2 ins.) diameter and 1 metre (3 ft. 3⅜ in.) long.

its axis A, carrying with it the pointer P to indicate its degree of angular displacement on the graduated circle. Generally this bar-magnet is parallel with the needle, the pointer of the compensator and the needle being both at zero; but when we wish to measure the amount of magnetism in the piece of iron I, the bar-magnet is made to pass through an angular displacement necessary to make it balance this force, and its index reading on the graduated circle is taken as the comparative value. The north pole of the compensator should be opposite the north pole of the needle, in order to render it almost astatic and consequently exceedingly sensitive.

In order to magnetise the iron I, if required, by an electrical current, a coil of insulated copper wire F is placed near C, the iron I then becoming the core of an electro-magnet. Now as this coil, independently of its iron core, acts upon the needle, its action must be balanced by an opposing coil G, on the opposite side of the needle. The position and power of the second coil G can be minutely adjusted by means of the lever H, which allows of finding a position where the two coils completely neutralise each other. If we introduce iron in the coil on either side, the balance is destroyed, and we have solely the magnetic influence of the iron core, the value of which we find by an equal opposing magnetism brought into play by the rotating magnetic compensator A.

A reversing key J serves to change the direction of the current, and thus any difference between north and south polarity in the iron core I can be observed. One Daniell cell is all that is required as a battery; but great care must be taken that its electromotive force is a constant, otherwise all variations in the battery would be read as variations in the quality of the iron itself; and we need in addition a series of resistance coils R from 10 to 100 ohms, in order to reduce the current sufficiently for bringing into range the whole series, from soft Swedish iron to cast steel. Separate and finer determination can then be made, by an extremely weak force for soft iron, and by full or increased battery power for tempered steel. A series of different sized coils to replace that at F is necessary, whenever we vary greatly the diameter of the iron core. The first size, with an

internal core-opening of one centimetre (0·4 in.), will test bars and rods of wire from one centimetre diameter down to the finest needle; but for larger bars, plates, &c., coils must be used which allow free passage for the iron into the core-opening. Great care and some practice are necessary in the use of the instrument, so as to ensure that the iron is placed in a neutral field; but when we have really obtained the necessary conditions, we can take several readings in a single minute, with an invariable result for the same kind of iron.

All irons and steels have some traces of remaining magnetism; it is therefore necessary that a double reading (north and south) should be taken by means of reversed currents. In this case the quadrant of the compensator scale is divided into 360° on each side of zero; and the total value of north and south polarity added together is that given in the following tables of magnetic capacity.

Several methods of observation can be employed with the magnetic balance, the usual one being that already described; but there are many others, such as magnetising all specimens to the same value and noting the amount of current required. We may also observe the remaining magnetism after the cessation of the current; the influence of a weak current after the passage of a strong one, &c. Many of these methods give interesting facts, particularly useful to those making researches upon the cause of magnetism.*

By means of this instrument the author has tested sixty brands of iron and steel, mostly in the form of wires. A wire 1 millimetre diameter and 10 centimetres long (0·04 in. and 4 ins.) was the standard size used, as we can more readily temper small wires than large rods. In all comparative experiments between iron of different grades, we must have one standard form to which all the rest must be similar in form and size. Thus we could not compare a square or flat bar with a piece of wire; but if all pieces have the same form, then any difference observed between them must be due to their comparative softness, from which we can deduce the quality and place of each in the range from soft iron to cast steel.

* The author has not patented this instrument, giving it freely to the scientific and manufacturing world.

Influence of Annealing upon the Molecular Structure of Iron and Steel.

The magnetic balance shows that annealing not only produces softness in iron, and consequent molecular freedom, but entirely frees it from all strains previously introduced by drawing or hammering. Thus a bar of iron drawn or hammered has a peculiar structure, say a fibrous one, which gives a greater mechanical strength in one direction than another. This bar, if thoroughly annealed at high temperatures, becomes homogeneous in all directions, and has no longer even traces of its previous strains, provided that there has been no actual mechanical separation into a distinct series of fibres.

Table I.

Influence of Annealing upon Swedish Iron, sample G.

	Approximate Temperature.		Degrees of softness indicated upon the Magnetic Balance.
	Cent.	Fahr.	
Wire hard-drawn as furnished by makers .	—	—	230°
Annealed at black heat	500°	950°	255°
,, dull red	700°	1300°	329°
,, bright red	1000°	1800°	438°
,, ,, yellow . . .	1100°	2000°	507°
,, ,, yellow white . .	1300°	2300°	525°

From Table I. we see that a regular increase of softness occurs as the temperature at which Swedish iron is annealed increases, the maximum being at a point under that of fusion.

Some difficulty was experienced in annealing all wires to the same standard. The method employed at first was to place the wires in an iron tube heated to the desired temperature; but the temperature of the tube was extremely variable, and it was also found that an interchange of carbon takes place between the tube and wires. Steel wires rapidly lose their carbon, and thus become softer at each

successive annealing; whilst the purest iron absorbs carbon, until it contains exactly the same proportion as the tube itself. It is well known that iron wires at red heat, placed in a porcelain tube through which a current of carburetted hydrogen is passing, will absorb sufficient carbon to become hard steel.

Experiments regarding the time required for perfect annealing showed that, whilst hard steel required several hours, soft iron might be cooled in a few minutes without losing its degree of softness; consequently, knowing the great value of high temperature, the author adopted the following method. The tube was heated to a white heat or otherwise, the iron wires to be annealed were introduced quickly, and the instant they had the same temperature, they were withdrawn and simply allowed to cool in the air. The wire employed being 1 millimetre diameter (0·04 in.), the whole operation was complete in two minutes. This is not suggested as the best practical method of annealing, although in the case of these wires it produced the best result; but the experiments show that, whatever method is employed, the heating should be as rapid as possible to a high degree of temperature, and the wire should cool in a completely neutral medium or atmosphere.

The facts regarding annealing, as pointed out by the measurement of the magnetic capacity of iron wires, have no doubt been in a great measure perceived by ordinary mechanical methods. The results of the author's researches may be thus formulated:—

1. The highest degree of softness in any variety of iron or steel is that obtained by a rapid heating to the highest temperature less than fusion, followed by cooling in a medium incapable of changing its chemical composition.

2. The time required for gradual cooling varies directly as the amount of carbon in alloy. Thus absolutely pure iron would not be hardened by rapid cooling, as in tempering; whilst steel might require several hours or days for cooling, in order to soften it, even in the case of pieces only 1 millimetre diameter (0·04 in.) Slow cooling has no injurious effect upon iron, when cooled in a neutral field: consequently, where time is no object, slow cooling may be employed in every case.

A wire or piece of iron thoroughly annealed must not be bent, stretched, hammered, or filed; the hardening effect of a bend is most remarkable, and the mere cleaning of the surface with sand-paper hardens that surface by several degrees on the scale.

The following Table II. shows the effect of annealing upon a series of wires, kindly furnished expressly for these experiments by Messrs. Frederick Smith & Co., of Halifax.

TABLE II.

Mark.	Description of Iron or Steel.	Magnetic Capacity.	
		Bright as sent.	Annealed.
		Degrees on Scale.	Degrees on Scale.
G	Best Swedish charcoal iron, 1st variety . .	230	525
F	,, ,, 2nd ,, . .	236	510
T	,, ,, 3rd ,, . .	275	503
S	Swedish Siemens-Martin iron . . .	165	430
H	Puddled iron, best best	212	340
Y'	Bessemer steel, soft	150	291
Y	Bessemer steel, hard	115	172
Z	Crucible fine cast steel	50	84

From the above Table it will be seen that annealing had a great effect on the iron wires, doubling their magnetic capacity, and that Swedish iron stands far in advance of puddled iron; consequently, for the cores of electro-magnets in telegraph instruments—as in fact for all electro-magnets—Swedish iron is the most suitable; and the magnetic balance may find a field of practical utility in measuring each core before it is used in an electro-magnet, and may also aid by its measurements in finding the best methods of annealing.

TEMPERING.

The influence of tempering upon the magnetic retentivity, or molecular rigidity, has been shown in every piece of iron or steel yet examined. Swedish iron hardens but 10 to 20 per cent. by tempering, whilst cast steel hardens 300 per cent.; * the molecular rigidity of tempered steel being 18 times greater than that of soft iron. The influence of different methods of tempering on crucible steel is shown in Table III., ranging from its ultimate molecular rigidity to its ultimate softness when annealed.

TABLE III.

Tempering of Crucible Fine Cast Steel, mark Z.	Plate 2. Fig. 5.	Magnetic Capacity.
Bright yellow heat, cooled completely in cold water	*a*	28
Yellow red ,, ,, ,,	*b*	32
Bright yellow, let down in cold water to straw colour	*c*	33
,, ,, ,, blue .	*d*	43
Bright yellow, cooled completely in oil . . .	*e*	51
Bright yellow, let down in water to white . .	*f*	58
Red heat, cooled completely in water . . .	*g*	66
,, ,, ,, oil	*h*	72
Annealed	*j*	84

We may therefore represent graphically a diagram which shall include all methods of tempering; and another diagram which shall include all varieties of iron, from the softest iron to the hardest steel, intermediate qualities of hard iron and mild steel finding their place between the two extremes. The first diagram is shown in

* For instance, in Table IV., page 47, the figure for Swedish iron No. 1 annealed is 525, tempered hard 435. On the other hand, the figure for cast steel annealed is 84, tempered hard 28. The reciprocals of these figures give what may be called a scale of hardness, as shown in Fig. 8, Plate 3.

Fig. 5, Plate 2, in which the figures are represented by lines (lettered as in Table III.) erected from points on a horizontal scale, to meet a diagonal line drawn at 45°. Thus the height of each line shows the magnetic value, and their distance apart shows the way in which they gradually approach the maximum. The second diagram is shown in Fig. 6, Plate 2, where the lines are lettered as in Tables IV. and V.

The numerous specimens of wires tested have been forwarded direct from the manufacturers, at the request of the author's friend, Mr. W. H. Preece, F.R.S., Electrician to the General Post Office. The chemical analyses of most of these wires have not been furnished; but Messrs. Frederick Smith & Co., of Halifax, not only supplied a beautiful series of wires, but had them specially analysed by Mr. Henry S. Bell, of Sheffield, in order that the results should be as exact as it was in their power to make them. The author therefore neglects in this paper all other samples except those of Messrs. Frederick Smith & Co.: they all stand between, or are included by, the two extremes of Swedish iron and cast steel.*

Table IV. on next page gives the complete results of the mechanical, chemical, and physical tests upon these wires. The tensile strength and electric conductivity are as furnished by Messrs. Frederick Smith & Co.; the chemical analyses are as given by Mr. Henry S. Bell; and the magnetic capacities of the bright hard-drawn wires, as also of the annealed and tempered wires, were determined by the author with the aid of the magnetic balance.

Table IV. will aid us in drawing several conclusions. Taken in conjunction with Table III., it shows—

1st. That the degree of temper in cast steel is dependent jointly on the heat to which it is raised and on the degree by which this is lowered in rapid cooling: the extremes in Table III. giving the relative molecular rigidity of the hardest and softest steel.

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* The author does not desire that Swedish iron should be considered as the softest of all possible irons, or tempered cast-steel as the final limit of hardness. They are simply the limits found during these researches; but these limits may possibly be widened by trying a more extended series of irons and steels.

TABLE IV.

Mark.	Description of Iron or Steel.	Electric Resistance per mile of 0·04 in. diam.	Tensile Strength per sq. inch.	Magnetic Capacity.			Chemical Analysis, percentages.						
				Bright hard.	Annealed.	Tempered hard.	Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.	Copper.	Iron.
		Ohms.	Tons.	Deg.	Deg.	Deg.							
G	Best Swedish charcoal iron, No. 1 .	191·52	28	230	525	435	0·09	trace	trace	0·012	0·06	trace	99·69
F	" " " No. 2 .	198·40	30	236	510	415	0·10	trace	0·022	0·045	0·03	trace	99·70
T	" " " No. 3 .	199·62	31	275	503	395	0·15	0·018	0·019	0·058	0·234	trace	99·44
S	Swedish Siemens-Martin iron . .	226·32	34	165	430	390	0·10	trace	0·035	0·034	0·324	trace	99·60
H	Puddled iron, best best . . .	259·92	30	212	340	328	0·10	0·09	0·03	0·218	0·234	0·015	99·11
Y[1]	Best homogeneous Bessemer steel, soft	266·52	35	150	291	255	0·15	0·018	0·092	0·077	0·72	trace	98·74
Y	" " " hard	312·69	50	115	172	60	0·44	0·028	0·126	0·103	1·296	trace	98·20
Z	Fine crucible cast steel . . .	350·08	55	50	84	28	0·62	0·06	0·074	0·051	1·584	trace	97·41

2nd. That a peculiar mild and homogeneous temper is obtained in oil.*

3rd. That the tempers, or degrees of hardness, when steel is let down through the various colours, vary with the kind of steel tempered, as well as with the heat from which it has been let down.

In these experiments the author has noticed that the highest degree of temper has not been obtained with wires containing relatively the highest proportion of carbon. The maximum thus far was obtained with but 0·62 per cent. of carbon; whilst in a series of steel wires, made expressly for these experiments, but in which the manufacturer stated only the amount of carbon, the results were as in Table V.

TABLE V.

	Mark.	Magnetic Capacity.		Carbon.
		Annealed.	Tempered.	
		Degrees.	Degrees.	Per cent.
Bessemer soft steel	Y^1	291	255	0·15
Steel made for these Experiments	S^1	348	206	0·40
,, ,, ,, ,, ...	S^2	250	160	0·55
,, ,, ,, ,, ...	S^3	209	133	0·60
,, ,, ,, ,, ...	S^5	195	107	0·75
,, ,, ,, ,, ...	S^4	144	61	0·65
Bessemer hard steel	Y	172	60	0·44
Fine crucible cast steel	Z	84	28	0·62

It will be seen that the hardness, as indicated inversely in the column "tempered," is not directly as the proportion of carbon: a marked example being the wire S^5 with 0·75 per cent. of carbon, which is far softer than the wire Z with 0·62. The author might

* The author has found, by a method more complicated than here described, and by the use of the induction balance, that all tempers heretofore tried (excepting those in oil) give a steel not homogeneous: and a temper let down to straw or blue has external strains differing from those of the interior.

here have doubted the truth of the magnetic balance, if he had not previously verified its results by mechanical tests. In order however to test the accuracy of the results, the wires S^5 and Z were bound together, heated together to the same temperature, and plunged together into cold water; this was repeated several times, with the invariable result that the wire Z with 0·62 carbon was glass-hard and could not be marked by a file, whilst the wire S^5 with 0·75 carbon could be easily cut by the same file. Again we notice that in Table IV. the wires T, of soft Swedish iron, contain precisely the same amount of carbon (0·15 per cent.) as those Y^1 of Bessemer soft steel in Table V.: but that, whilst Y^1 is comparatively hard when tempered, it does not become greatly softened by annealing. This is due probably to its greater proportion of some other ingredients. Similarly the wire S is much softer than H in Table IV., both having the same percentage (0·10) of carbon. The hardness of H when annealed is probably due to its greater proportion of phosphorus or some other substance.

It may be too soon to try to correlate with the corresponding chemical analyses the physical changes occurring in tempering: but the author believes he has shown reason to hope that we may eventually obtain, by uniting chemical with physical analysis, a more clear insight into the mysteries of iron and steel.

Proposed Dividing Line between Iron and Steel.

Mechanical tests, as well as chemical analyses, have failed to find any distinct line of separation between the numerous varieties of iron and steel. The physical method which the author has employed shows clearly that there is no dividing line between iron and steel. If we glance at Fig. 6, Plate 2, we see that we have a continuous series from the softest iron to the hardest steel, and between these extremes we have every variety of intermediate quality. In point of fact the sixty brands which have been tested fill up all the gaps: and by their means we could choose irons gradually hardening into steel, or steels gradually softening into iron. Thus ordinary iron is physically a soft steel, and steel a hard iron. All are hardened by temper; all are hardened by mechanical treatment, as hammering

and rolling; all are hardened by strains and stresses of any nature whatever: the difference, though large, is only in degree. At the extreme end towards iron, mechanical hardening has a greater effect than tempering. At the steel end, tempering has a greater effect than mechanical hardening. We might here suppose we could find a physical dividing line: but the author has found some mild steels to stand just on that dividing line which had previously appeared the most satisfactory. We are thus forced to adopt an arbitrary line. Neither mechanical nor physical methods will suffice to overcome the difficulty. Mechanically a certain tensile strength has been proposed —the objection to which is that unless we take note of the physical conditions (such as whether soft, tempered, &c.) we shall have very different magnetic readings for what would stand as the same material. The addition of the ultimate elongation might to some extent weaken this objection, but would not remove it. The physical method would allow us to fix upon a certain molecular rigidity, or difference in the readings of the same metal annealed and tempered, as the boundary; it would however have all the objection of being a purely arbitrary line. Chemical analysis also fails to show a dividing line, since the same proportion of carbon is accompanied by very different physical results, if sulphur, phosphorus, &c., be present. In the author's researches he has adopted the plan of simply reading an unknown piece of iron or steel in its annealed state: if the figure stands above 400° it is classed as iron; if below, as mild or hard steel according to its magnetic capacity. This classification happens to agree with that in general use at present, and suffices as a general division.

RELATIONS OF PHYSICAL FORCES IN IRON AND STEEL.

Iron is by far the richest of all metals in its physical nature. It stands almost alone in its magnetic qualities, as well as in its tempering properties; and, while there is an evident relation between capacity for temper and loss of magnetism when tempered,* so these

* This is shown in Table IV. and Fig. 6, Plate 2, where the proportion of magnetism lost by tempering is seen to increase markedly as we pass from soft iron to hard steel.

experiments show an intimate if not absolute relation between the electric conductivity of iron and its magnetic capacity. In Table IV., in the column of electric resistances as given by Messrs. Smith and Co., we find a progressive increase of resistance, just as we find a progressive decrease of magnetic capacity. And there is an exact correspondence between the two variations: as is shown graphically in Fig. 7, Plate 3, where both sets of figures are marked off on horizontal scales, and then lines are projected upwards for magnetic capacities, and downwards for electric resistances, to meet on a common diagonal line drawn at 45°. It will be observed how nearly the two vertical lines coincide for each of the respective samples. The molecular rigidity, observed by the author as the cause of hardness, gives at once decreased magnetic capacity and increased electric resistance; so that from the magnetic capacity we might deduce its electric resistance, and *vice versâ*. A very remarkable phenomenon is that this only holds true in the limited sphere of elastic rotation, which the author has already described.

This demonstration the author believes to be of great theoretical value; and in a future paper, upon the theory of magnetism, its importance will be shown. In the present paper the author has tried as far as possible not to bring theoretical considerations forward; in the results presented we are dealing with proved facts.

Another extraordinary relation of physical to mechanical tests may be mentioned. In Table IV. the tensile strength bears no relation either to the magnetic or to the electric qualities. On increasing the electromotive force in the magnetic balance, all the readings became confused; there was no longer any fixed relation as to hardness, or as to any other quality. But on again forcing the magnetism to a very high point, the figures for magnetic capacity were found to bear exactly the same relation to one another as those for tensile strength. This however may have been only an accident, as it seems true at present in relation only to the wires in Table IV.; but it gives hope that by a new method we may some day be enabled to deduce from magnetic capacity not only electric conductivity but also tensile strength. Already in Table IV. we notice a close relation between molecular rigidity, as indicated by

the figures for the annealed wires, and tensile strength. This is shown graphically in Fig. 8, Plate 3, where the reciprocals of the figures for the annealed wires are used to form a scale of hardness, and it is seen that the figures for hardness rise with the figures for tensile strength. The only exception is the wire H, but the cause of this is clearly the small difference between its magnetic capacity as annealed and as tempered.

Leaving aside all theoretical considerations and hoped-for improvements in the methods of observation, the author believes he has demonstrated clearly that, by the aid of the instrument and methods described, we can at once determine the physical state of iron, as influenced by tempering and by mechanical hardening, from the ultimate degree of softness to that of hardness: and that we can at once determine the best iron for electro-magnets, and the best methods of softening it, as well as the best steel for permanent magnets, and the best temper to be given to it. He therefore ventures to hope that the Magnetic Balance will prove an aid of no small value in all researches into the physical state of iron and steel.

Discussion.

Professor HUGHES said the object of the research described in the paper was at first to find out what had long been a mystery:—whether magnetic capacity and electric conductivity were the same. That was a scientific subject, properly belonging to the electrician, and one in which he himself was much interested. But in order to find it out, he was obliged to study the nature of iron and steel; this led him to the study of tempering, and this again obliged him to make an instrument that would tell what the degree of tempering was. What had been said in the paper was perfectly true with regard to the relation between the magnetic capacity and the electric conductivity of wires; and he exhibited sixty-four different

samples of wire, running through the whole scale from the extreme of softness to that of hardness. Whether the same relation would hold good with large bars he could not at present say, having tried only four or five varieties in that form. Taking the short piece of wire which he now held in his hand, the operation of ascertaining its temper was extremely simple, not much longer than that of weighing the piece in an ordinary balance. If he wanted to know whether it was steel or iron, or whether it was hard or soft iron, he simply inserted it inside the magnetic coil F (Fig. 1, Plate 1) and then connected the battery. It would be seen that the needle N was at once swung over to one side; he then turned the bar-magnet round until it brought the needle back to zero. The pointer on the bar-magnet now indicated 150° on the scale; and 150° was therefore the value of that particular piece of wire, which he consequently knew to be of extremely soft iron. This of course would be known also by testing it with a file; but the reading on the magnetic balance afforded a far closer appreciation of its exact character than could be derived from any mechanical tests. The recent interesting paper by Mr. Hackney on the Testing of Iron* appeared to deal with exactly what the magnetic balance was capable of doing. That paper aimed at the adoption of a standard form of test-piece for breaking; and when engineers wanted to know the quality of a particular piece of iron, they broke it, thus of course destroying it, and then proceeded on the assumption that another piece, which they did not break, was of the same quality and strength as the piece which had been broken. But now, if he wished to send to a friend in America one of the best and softest pieces of iron, he could test it by this magnetic balance without breaking it, and could feel sure it was the finest piece that it was possible to have, and could therefore send it with full confidence. By this instrument he was able to test not only small pieces but long pieces. If there were a mile of wire, it could be tested by a method of winding and unwinding, and ascertaining its magnetic capacity continuously as it passed through or across the

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* Institution of Civil Engineers, Proceedings, vol. lxxvi.

instrument. As it would be very tedious to watch a whole mile of wire, he intended to contrive that the needle, when it swung over, should be made to ring a bell; so that directly the bell rang it would be known there was a flaw at that part. If the conclusions arrived at in the paper were true, the advantage of the magnetic balance to the manufacturer of iron and steel would be enormous, and it would be impossible to foresee the extent of its utility; but at present he could not say how far these conclusions were true, as they formed only the threshold of the subject. His trials had been made with small wires, because these could be tempered with great facility; it was impossible to get the temper uniform through the inside of a large bar, but with small wires he could do what tempering was necessary. For mechanical engineers it would require a great amount of capital and labour to develop this system of testing, and it could only be done by a large institution, as he did not suppose any private individual would be willing to incur so great a sacrifice for the good of science. At any rate there was here a great field for future research with large pieces of iron and steel, inasmuch as thus far with large bars he had tested the extremes only, but not the intermediates of temper. It would certainly be a great mistake to suppose that the magnetic balance could be used without previous electrical knowledge. It was necessary to select the coils and arrange them in accordance with the testing that had to be done. Flat pieces would require flat coils, long pieces long coils; in fact it would be necessary to design the coils for the purpose intended.

It was possible to obtain an enormous amount of information by this instrument. At present he had been engaged for some time in trying to find out the cause of magnetism; and in this study he used the magnetic balance constantly; indeed he could not get along without it. One experiment would suffice as an illustration of its utility. Taking a piece of steel and magnetising it, he placed it in a glass vase; and in order to see what was inside the magnet, to see how its interior was constructed, and to measure its magnetic force, he then poured nitric acid on it, so that it was gradually dissolved from the outside inwards. With the instrument he kept

on following and noting the changes of polarity, and plotting them out in curves. In that way he was able to go through every bit of the magnet, from the outside to the interior. The instrument was therefore of great value to himself; and if engineers made use of it, he believed it would be found equally valuable to them. Not being a master of the art of tempering or annealing, he had learned it simply through this instrument, which he had now brought forward in the present paper in order that he might have the advantage of hearing the opinions of those who were experienced in the practice of tempering and annealing.

Professor W. CHANDLER ROBERTS, F.R.S., said no one could appreciate more highly than he did the beautiful instruments of Professor Hughes, who had been kind enough to allow him to conduct experiments with them as soon as they had been made. He spoke especially of the induction balance,* which had already rendered very great service to metallurgists, and had passed into practical use. It was no longer necessary at the Mint to assay a doubtful sovereign; it was only necessary to put it into the induction balance, which at once revealed its character. He had also repeated Professor Hughes's experiment with the torsion balance, and had quite confirmed his results.

It was some little disappointment to himself to hear that there was no true line of demarcation between iron and steel; but the fact appeared to be undoubted, after the admirable results given by Professor Hughes. There did appear to be a possibility of determining with very great accuracy the amount of carbon contained in the steel. It had been stated by Professor Hughes that the curve of magnetic capacity did not quite follow the percentage of carbon, but was modified by hardening and tempering. But he did not know whether Professor Hughes had noticed that in the specimens Y and Z in Table IV., which were abnormal with regard to their magnetic capacity, the percentage of manganese was extraordinarily high. Manganese imparted to iron the same effect as carbon with

* See Proceedings Inst. M. E. 1883, page 72.

regard to capacity for receiving hardness, only in an enhanced degree; and he thought the presence of manganese must be the cause of the discrepancy observed by Professor Hughes in those two specimens. Again, the high tensile strength of those two wires seemed to prove the same fact, because manganese increased the tenacity of iron up to a certain point, as did carbon; and he considered that the magnetic curve would be found to be strictly in accordance with the chemical composition of the sample tested. There could be no question that from a practical point of view the magnetic balance was an instrument of the greatest possible value; Professor Hughes had clearly shown that by its aid every minute gradation of hardness could be determined. In the only application of hardening that directly interested himself—namely the formation of dies for coinage purposes—this was a matter of the greatest possible importance, because a very small difference in the degree of hardness would make all the difference in the life of a die, that is, in the number of pieces it would strike. He was therefore convinced that the magnetic balance would be to the metallurgist a most valuable ally. If he might venture upon a little criticism, it would be to ask whether the word "tempering," as used in the paper, was not employed in a somewhat confused sense. Tempering he thought was always understood to mean letting down a piece of steel which had been hardened up to its maximum point—annealing it in fact through varying shades of softness. In this respect he thought there was some little confusion in the statement on page 38:— "Similarly, when we temper annealed iron and steel, we find that we can follow out each degree of *temper* up to ultimate molecular rigidity;"— where he should prefer to say each degree of *hardness*. It was true the expression "temper let down to straw or blue," in the footnote on page 48, seemed to put the matter in a somewhat clearer light; and this small criticism did not in any way detract from the great value of Professor Hughes' interesting paper.

Mr. E. A. Cowper enquired, in reference to the wires received by Professor Hughes from the manufactory, whether he had at all investigated the difference between surface hardness and interior

hardness: because bench-hardening hardened the wire materially, and unless it were steel wire, and were tempered to something like dark blue, it was found impossible to go on continually drawing it down to a smaller size, and it had to be annealed after every two or three draws through the die. If hardened to a dark blue temper, ordinary steel wire would draw on for ever. That was the way the Austrian music wire had been made many years ago, and it was the way in which all the hard-drawn wire for making wire-ropes for steam-ploughing was now made. There was one rough mechanical way in which he had himself some years ago tried the hardness of various samples of iron and steel:—namely, by taking some good saw-files, hardened to a definite hardness, and carefully lowering them to different degrees of colour, so that he had a series of four or five files of different tempers, down to a soft file. With those he could pick out various samples of iron and steel, and could tell directly the difference between 0·2 and 0·3 per cent. of carbon in steel, by finding which file would touch one and which would touch another.

With regard to the word "temper," he agreed with Professor Roberts in wishing to define "hardening" as it had always been defined, namely making the steel as hard as could be; tempering being hardening or lowering to a certain degree. He would ask Professor Hughes to be good enough to harden steel somewhat harder than he had yet done. That could be simply done by making it as hot as it would stand, and dipping it quickly in a large bath of cold mercury, which hardened it much more than cold water. In fact a piece of steel so hardened could be made to cut glass easily.

Mr. J. C. FELL observed that the paper concluded with the statement that a variety of results might be obtained with the magnetic balance, amongst which it was mentioned that the best steel might be determined for permanent magnets, and the best temper to be given to it. As he was personally interested on that point, he might be permitted to say that he could not see anything in the Tables given in the paper which would enable the coercitive force or retentive power of the steel after magnetisation to be inferred

from its inductive or magnetic capacity. It was to be inferred from the paper that the retentive power would be inverse to the magnetic capacity; and he wished to ask whether this had been so far tested that the figures of capacity might be taken as being inverse to those of retentive power. This was an important point when dealing with steel for permanent magnetisation. As to the hardening effect of phosphorus, referred to in the paper (p. 49), there had many years ago been somewhat indefinite allusions to the steely effect produced by phosphorus upon iron when in combination with it; and it had been stated that this effect depended upon the combination of carbon with the iron at the same time, and that the proportion of carbon present should be very small. He supposed it might be quite possible to obtain a combination of phosphorus and iron, with the smallest possible percentage of carbon, so as to get a metal somewhat analogous to phosphor-bronze, which was already well known in mechanical engineering.

They would all be very much obliged to Professor Hughes if he could give an idea how practically to obtain the hardest possible temper for steel, with the least possible tendency to fly while the hardening was being carried out. That was perhaps more a practical than a scientific question; but the point was one which offered a great deal of difficulty where there were holes pierced through the steel. In such cases it was extremely difficult to get a hard temper such as would be desired for the purpose of magnetisation of the steel, without causing it to fly through the holes. He had been puzzled with the results of some experiments that he had been trying, for tempering compound steel and iron rings to the hardest possible degree without causing them to separate or fly; and he attempted to do it by tempering them in hot water, believing that by lowering from a sufficiently high temperature to the even temperature of boiling water, 212° Fahr., a considerable chilling would be effected at a rapid rate, but not to so low a temperature as by the use of cold water or mercury. The result however had been that the steel was not harder than when it was considered to be annealed; the effect, in fact, was *nil*. He did not know whether this would be any new information; but he mentioned

it as one fact among others, the accumulation of which might be useful to Professor Hughes.

Mr. J. G. Mair asked whether experiments had been tried with chilled cast-iron and with ordinary cast-iron. There seemed to be a difference of opinion as to the relative properties of chilled cast-iron and ordinary cast-iron; and he thought the magnetic balance might throw some light on that point.

Mr. Arthur Paget, referring to the enquiry of Professor Chandler Roberts as to whether the term "tempering" was used consistently throughout the paper, thought Professor Hughes' method of employing the word was a most admirable way of following the example of the French; and the sooner they realised that, when speaking of steel of a certain temper, this did not mean necessarily that the steel had been made hard and had afterwards been made less hard, the better. He thought therefore that Professor Hughes, in addition to the many obligations he had conferred upon them, had taught them a lesson, that they had better leave out any such distinction altogether, and understand that the term "tempering" was properly used irrespective of lowering the temper; and he thought this view was gradually coming into general use among engineers.

Professor Hughes in reply said that, with regard to manganese taking the place of carbon in producing a hardening effect, he himself had suspected that it was so; and he was glad to find that Professor Chandler Roberts agreed with the view he had entertained.

As to the use of the word "tempering," Mr. Paget was quite correct. Having himself resided a long time in France, where "tempering" was the word used, and a little time in Germany, where it was called "hardening," he had thus a choice of words; and he preferred the word "temper" for this reason. The magnetic balance showed that, whether a piece of iron were bent, or drawn, or hammered, or pressed, or were subjected to any other mechanical action, it was thereby hardened. But tempering was quite different; it was suddenly cooling from a high temperature to a lower. If he

had said "hardening," he should have had to define the kind of hardening: whether by bending or by twisting or by hammering or by rolling, whether mechanical hardening or otherwise. It would certainly be a good thing if some fixed word were used: and he did not see any objection to "tempering," which appeared to him an excellent term.

In reply to Mr. Cowper's enquiry, he had tested the tempering, not only of wires, but also of extremely thin flat surfaces; but he had never drawn any of the wires after they were tempered; they had been carefully tempered and then let down, and not touched afterwards. The wires were as they had been originally sent to him by the manufacturer, from whom he had received a large sample of each kind. There was a mean error of 2 per cent. in the same wire; although the samples were all cut off the same piece, there was always a slight difference, and he was obliged to take the mean; the range was not a wide one.

With regard to the question of the coercitive force and the best steel to be used for magnetism, he had made a very large number of tests. It was easy to determine whether any piece of steel was magnetic by simply inserting it in the coil of the magnetic balance, turning the current on, and observing the reading on the scale. On then turning the current off, the remaining magnetism was shown by the index not returning to zero, but pointing to a certain degree on the scale, according to the quality of the steel tested. In this way the value of any piece of steel as a natural magnet or as an electro-magnet was ascertained in the most perfect manner. He had not tested cast-iron, and could give no information upon it.

The CHAIRMAN said he might mention that the Council had under consideration the making of further research into this very interesting subject; and he had no doubt they would have the advantage of the support of Professor Hughes, to whom he was quite sure the Members would all join with himself in rendering their hearty thanks for his able paper.

MEMOIRS

OF MEMBERS DECEASED IN 1883.

CHARLES BERGERON was born in 1808, and entered the École Polytechnique in 1828, and in 1830 the École d'Application at Metz. He then quitted the government service, and turned his attention to private industrial enterprise. From 1834 to 1840 he took an active part in laying out and constructing the Rive-de-Gier Canals and other canals of the Rhône district. In 1846 he was on the engineering staff of the St. Étienne and Lyons Railway, having previously made trials of steel rails on some lines about 1842. In 1846 he became engineer-in-chief of the Paris and Versailles line on the left bank of the Seine. He had charge of constructing the line from Mantes to Mézidon; then, quitting the Western Railway of France, he undertook the working of the Western Railway of Switzerland. Afterwards he engaged in the construction of cheap railways in France, including that from Belleville to Beaujeu (Rhône). In 1875 he was appointed engineering representative in England of the French railways, having previously drawn up several important reports, particularly in 1865, respecting various professional visits he had paid to England. His death took place in Switzerland on 25th August 1883, at the age of seventy-five. He became a Member of the Institution in 1879.

AMBROSE EDMUND BUTLER was born at Kirkstall Forge in 1816, and died at his residence, Kepstorn, Kirkstall, on 16th August 1883, at the age of sixty-seven. He was brought up to the iron trade at those works, which had been carried on by his family since 1779; and in 1841 he entered into the partnership, of which he continued an active member till his death. He did not himself enter into the mechanical engineering part of the business, which was conducted by his brother, the late Mr. J. O. Butler; but confined himself to the iron manufacturing department, which under his care increased very largely. He introduced the rolled shafting that requires no turning,

with which the name of Kirkstall Forge is now so thoroughly identified. He became a Member of the Institution in 1856.

JEAN BAPTISTE PROSPER CLOSSON was born on 7th June 1840, at Souppes, in the department of Seine et Marne, France; and died in Paris on 23rd November 1883, at the age of forty-three. He studied at the École Centrale des Arts et Manufactures, which he left in 1863 with the diploma of engineer. For several years he was engaged in the manufacture of cement, having charge of works in the department of Nièvre. Subsequently, in connection with Messrs. Bichon and Co. of Paris, he was occupied in the development of various inventions, such as the Vapart disintegrator, upon which he read a paper at the Paris Meeting of the Institution in 1878. He also produced numerous inventions of his own, particularly in connection with the economical manufacture of magnesia by means of waste products, such as the waste water from hydrochloric acid manufacture. The chemically pure magnesia so obtained he intended employing principally for furnace-linings in the Thomas-Gilchrist process, as well as for hydraulic cement, for artificial manure, for treating sewage, and for removing incrustation in boilers; on these subjects he published much valuable information. He became a Member of the Institution in 1878.

EDWARD DODSON was born on 24th December 1841, at Handsworth Hall, near Sheffield; and began business in 1865 with Mr. W. Lawson Austin, under the style of Austin and Dodson, steel and file manufacturers, Cambria Works, Sheffield. He continued to take an active part in the business until his death, which took place at his residence at Rutledge on 16th February 1883, after a short illness, in the forty-second year of his age. He became an Associate of the Institution in 1882.

BENJAMIN SAMUEL FISHER was born on 31st August 1836, at Nailsworth, Gloucestershire. He first worked as a pupil for two years with Mr. John Hayes of Stony Stratford, and was then apprenticed for three years at the Vulcan Foundry, near Warrington.

He then entered the employment of the Manchester Sheffield and Lincolnshire Railway, and in 1860 went to the shops of the London and North Western Railway at Wolverton. In January 1862 he went to India, as assistant locomotive superintendent under the late Mr. George Anderson on the Bombay Baroda and Central Indian Railway. In 1865 he returned, having completed his engagement, and became locomotive superintendent of the Sirhowy Railway, where he remained until the spring of 1870. He then became locomotive superintendent of the Taff Vale Railway; and about the end of 1873 he received the appointment of locomotive superintendent to the Somerset and Dorset Railway; this post he retained till his death, which took place at Burnham on 28th April 1883, at the age of forty-six, from gangrene in the foot through a poisoned corn. He became a Member of the Institution in 1871.

JOSIAH GIMSON was born at Leicester on 29th November 1818. After having served his apprenticeship to Messrs. Cort & Co., ironfounders, he started in business with his brother Benjamin under the name of Gimson & Co., as general engineers and machinists. During the early period of their partnership, some thirty years ago, the elastic-web trade commenced, and they devoted their attention to manufacturing the special machinery it required, which for many years formed by far the most important branch of their business. Of late years that particular trade having been partially lost to Leicester, Mr. Gimson turned to the construction of special machinery for the boot and shoe manufacture, which has developed to a great extent in that town; he introduced improved machinery for the purpose, and machinery of this class has since continued to be extensively made by his firm. Later Messrs. Gimson & Co. added ironfounding and boiler-making to their business, building extensive works furnished with every facility in the shape of machine-tools and appliances for turning out a large quantity of work; they also gave more attention to engineering proper, making a special feature of large pumping engines for water and sewerage works. After his brother's death in 1862, Mr. Gimson carried on the business alone, the title of the firm not being altered. In the autumn of 1880

he had a serious illness, from which he apparently recovered, and resumed his duties; but his strength was impaired, and in the spring of 1883 he again became ill, and gradually sank until his death took place on 6th September 1883, in the sixty-fifth year of his age. He became a Member of the Institution in 1878.

JOHN INGLIS was engaged from 1846 to 1864 in railway bridge work, mill work, coal mining, &c., in Scotland and in London. He then went out to Hong Kong, and was engaged in erecting the Mint there, of which he acted as superintending engineer. On the closing of this establishment in 1868, he was engaged in constructing the graving dock for the Union Dock Co., of which he was appointed manager. On the amalgamation of this concern in 1871 with the Hong Kong and Whampoa Dock Co., he commenced business on his own account at the Victoria Foundry, Praya East, designing and building steamers and machinery; and afterwards established himself as a consulting engineer in Hong Kong, until seized with an illness which terminated in his death on 26th April 1883, at the age of fifty-three. He became a Member of the Institution in 1882.

JABEZ JAMES was born on 17th March 1810. After serving a seven years' apprenticeship, from 1826 to 1833, to his father, who was a smith and bell-hanger, he worked four years as journeyman to Mr. R. Miller, a locksmith and bell-hanger, to whose business he succeeded in 1837, and soon became largely engaged in artistic metal-work and model-making. Among his finest models was that of the Britannia Tubular Bridge, which obtained a prize medal at the Great Exhibition of 1851; also that of the Kieff Suspension Bridge, and that of the paddle-wheel engines of the "Great Eastern" steam-ship. He constructed portions of the metal-work for the Clock Tower and Palace at Westminster, and for several other public buildings; and was also engaged in raising and hanging the bells in the Clock Tower, and in repairing the structure of several cathedrals. While so occupied he established a factory in Lambeth, where, in addition to engines and other machines, he constructed machinery of special descriptions for the Bank of England, the

Mint, and other government establishments, as well as for many private firms. For the manufacture of small-arms he devised and made the very exact gauges and machines required; and also apparatus for the manufacture of gunpowder. He constructed machinery for printing, stamping, and file-cutting, and for making screws and tin boxes; also air-engines and refrigerating apparatus, and many other kinds of machinery. Having in 1875 met with a serious accident, which rendered him almost a cripple and was followed by frequent attacks of illness, he died on 9th January 1883, in his seventy-third year. To the very last he was occupied in bringing out apparatus for electrically lighting railway carriages. He became a Member of the Institution in 1856.

JOHN LENNOX KINCAID JAMIESON was born on 27th March 1826, at Milton of Campsie, near Glasgow, his father being a miller. In 1844 he was apprenticed to engineering at the Canal Basin Foundry in Glasgow, and remained there until 1850. He then went as manager to Messrs. Thomas Grendon and Co., Drogheda Iron Works, Drogheda, till 1852; and afterwards to the Railway Foundry, Leeds, till 1854. Next he went for about twelve months as third-class assistant on board the "Majestic" in the Royal Navy, and was appointed to the second class in March 1855; he served in the Baltic under Sir Charles Napier, and was at the bombardment of Bomersund, where he received a medal. In 1856 he became superintendent engineer of the Pacific Steam Navigation Co., in charge of their repairing establishment on the island of Taboga in the bay of Panama. During the ten years that he occupied this position he was intimately connected with the practical working and development of the compound marine engine; the earliest of these engines supplied to the Pacific fleet by Messrs. Randolph Elder and Co., of Glasgow, were of the four-cylinder diagonal type, but were succeeded by two-cylinder engines with intermediate steam-receiver. Returning home in 1866, he shortly afterwards became general engineering manager to Messrs. Randolph Elder and Co.; and on the reconstitution of the firm in 1870 he became a partner. In 1872 the three-cylinder compound marine engine was introduced by his firm into the steamers "Iberia"

and "Liguria," which they built for the Pacific line. In the beginning of 1879 he retired from the firm; and occupied himself actively in much prominent public work, until his death on 2nd July 1883, at the age of fifty-seven. He became a Member of the Institution in 1870.

JOSEPH JESSOP was born on 27th March 1825, at Horbury, near Wakefield. At the age of fourteen he was apprenticed to Messrs. Green Atkinson and Holt, Wakefield, where he acquired considerable mechanical experience, particularly in connection with colliery machinery. In 1847 he entered the locomotive works of the Lancashire and Yorkshire Railway, Manchester, and was engaged in the early attempts at lighting by electricity the Victoria Station in Manchester and one of the tunnels on the line. Subsequently he started some small engineering works in Marble Street, Leicester, under the firm of Ryder and Jessop; as the development of the business progressed, larger premises were secured, and Mr. Jessop, making steam cranes and hoisting machinery his speciality, became connected as partner in Leicester with Messrs. Appleby Brothers of London, until in 1880 the Leicester firm became Joseph Jessop and Son. In 1875-76 he twice visited the Crimea, for the purpose of arranging and fixing machinery for lifting heavy guns for the new Russian fortifications near the Black Sea. His death took place at his residence, Belgrave, Leicester, on 31st March 1883, at the age of fifty-eight, after an illness of several weeks. He became a Member of the Institution in 1878.

JAMES GASCOIGNE LYNDE was born in London on 25th January 1816, and served his pupilage under the late Mr. James Simpson in the office of the Chelsea Water Works, of which his father was then secretary. In 1839 he was employed on the Hull and Selby Railway under Mr. James Walker, and remained there until 1841, when he was taken into partnership by Mr. Simpson, with whom he had charge of the Chelsea and Lambeth Water Works, and carried out new water works and other engineering projects in various large towns. In 1848 he commenced practice on his own account; and in

1857 he was appointed city surveyor at Manchester, which position he retained for twenty-one years. During that period he carried out the construction of the Prestwich reservoir for supplying the higher portions of the district, and the laying of a 30-inch main from Godley reservoir to Prestwich; improvements of the river Medlock; the construction of the Smedley viaduct, the Waterloo and Princes' bridges over the river Irwell, the gas works at Bradford Road, the Alexandra park and southern cemetery, the Philip's park and cemetery, and the widening of Deansgate. At the end of 1878 he retired, in order to enter into partnership with his son, with whom he practised as consulting engineer in Manchester up to the time of his death on 15th March 1883, at the age of sixty-seven. He became a Member of the Institution in 1854.

Thomas William Rumble, F.R.S.E., was born in London on 26th December 1832. After receiving part of his education at the Reading Grammar School under the celebrated Dr. Valpy, he entered at an early age the office of his father, an architect, where he was taught the rudiments of his profession. Tiring of the routine of the drawing office, he went to America, where after many adventures he was appointed in November 1850 assistant engineer on the Central Railroad of New Jersey, being then barely eighteen years of age. He remained in America till June 1852, during which time he was actively engaged in laying out the Erie and Forest Lawn cemeteries, superintending the building of the Berks County baths, the Buffalo public washhouses, &c., and occasionally giving lectures on architectural and engineering subjects. Almost immediately on his return to England he obtained work in Kensington, superintending the building of All Saints' church, and the laying out of the Kensington Park estate. In October 1853 he went out to Bombay as assistant engineer on the Bombay Baroda and Central Indian Railway, then in course of construction; but an attack of fever obliged him to return to England in February 1854. He next obtained the post of engineering superintendent of the Arthington Extension Water Works, Leeds, under Mr. Hawksley, where he remained till the completion of the work. Returning to

London he was for short periods draughtsman in the offices of Messrs. Conybeare and Birkinshaw, the London and South Western Railway, &c., until in 1857 he was appointed engineer to the Atlas Steel Works, Sheffield, then entirely in the hands of Mr. (now Sir) John Brown. In 1862 he commenced practice in London as a civil and mechanical engineer. In 1869 he paid a second visit to the United States, and spent six months in visiting many engineering shops, and acquiring a thorough knowledge of the recent mechanical improvements. At the beginning of 1872, with the view of obtaining information for the National Safe Deposit Co., then about to be formed in London, he was again in New York, and visited the various safe-deposit buildings in that city, and in Philadelphia, Boston, and Halifax, as well as the ruins of Chicago, where after the recent great fire he inspected the vaults and safes remaining intact. On returning to London he designed the safes, strong rooms, buildings, and other arrangements for the National Safe Deposit Co., which were afterwards carried out under his superintendence at the corner of Queen Victoria Street. In 1876 he obtained the position of chief engineer of the Southwark and Vauxhall Water Works; and in 1878 he successfully laid a 30-inch main under the Thames at Richmond without the aid of dams, by dredging a trench across the bed of the river, and lowering into it the several lengths of pipe previously put together with ball-and-socket joints. Towards the end of 1881, excessive overwork and the responsibilities of his position began to tell on his health; and having, after still another year's work, vainly sought recovery in rest, he died at Bonchurch, Isle of Wight, on 21st April 1883, at the age of fifty. He became a Member of the Institution in 1860.

JOHN FREDERICK SEDDON was born in Liverpool on 25th May 1848, and received his early training as a mining engineer under Mr. Greener at the Pemberton Collieries near Wigan, and afterwards under Mr. Alfred Hewlett at the Wigan Coal and Iron Works. He then became manager and part proprietor of the Great Harwood Collieries near Accrington; and continued in that position till the latter part of 1883, when he established himself in practice as a consulting mining engineer. Only a month later, after having been

actively engaged in the explorations and attempts to rescue the colliers on occasion of the explosion at Moorfield Pit of the Altham Collieries, Accrington, he was being driven home late at night on 7th November 1883, when he was thrown from the vehicle and killed by the fall, in the thirty-sixth year of his age. He became a Member of the Institution in 1873.

Joseph Shuttleworth was born in the parish of Coningsby, Lincolnshire, on 12th July 1819. In 1842 he joined his brother-in-law, Mr. Nathaniel Clayton, in establishing the firm of Clayton and Shuttleworth, Stamp End Iron Works, Lincoln, for the manufacture of agricultural implements and machinery. In 1845 they produced the first of their portable engines, which with thrashing machines constituted thenceforth the chief specialties of their works. While continuing to take an active part in the management of this extensive business, Mr. Shuttleworth also devoted a large part of his time to numerous public enterprises. He was for many years a member of the council of the Royal Agricultural Society, in the success of which he took the deepest interest. His death took place at his residence, Hartsholme Hall near Lincoln, on 25th January 1883, in the sixty-fourth year of his age, after an illness of several weeks. He became a Member of the Institution in 1859.

Sir William Siemens, D.C.L., LL.D., F.R.S., was born at Lenthe in Hanover on 4th April 1823. He was educated at the Gymnasium at Lübeck, afterwards at the Polytechnic School at Magdeburg, and later at the University of Göttingen, where he studied in 1841 and 1842 under Wöhler and Himly. In 1842 he went for a short time to the engine works of Count Stolberg. In March 1843 he first came over to England, to introduce a joint invention by himself and his elder brother Werner in electro-plating, which was taken up by Messrs. Elkington and Mason of Birmingham. In 1844 he came over again with another invention, also worked out with his brother, namely the chronometric governor, which has been applied by the Astronomer Royal for regulating the motion of the great transit and touch-recording instrument at Greenwich Observatory, where it still

continues to be employed. This invention brought him into contact with the engineering world, and fixed him permanently in England. The anastatic printing process, for reproducing old or new printed matter, was another early invention of his, which found favour with Faraday, and aided in obtaining for its author an entry into scientific circles. Next year, in 1846, he invented a double-cylinder air-pump.

The first application of his regenerative system, for saving heat generally wasted, was made in 1847, when he constructed in the works of Mr. John Hick, Bolton, a 4 horse-power engine, having a condenser provided with regenerators, and using superheated steam. The direction in which he was then working led to the paper he presented to the Institution of Civil Engineers in 1853 on the conversion of heat into mechanical effect. In 1858 he established the firm of Siemens Brothers, for the manufacture and laying of submarine telegraph cables and land lines, and for the construction of electrical instruments and machines. About the same time he was engaged with his youngest brother Frederick in the invention of the regenerative gas furnace, of which the first practical application was made in 1861. Experimental works were erected in 1866 at Birmingham, where the process of producing steel on the open hearth of a regenerative gas furnace was gradually matured; and in conjunction later with M. Martin, of Sireuil, France, the Siemens-Martin process was brought into practice. His electrical resistance thermometer and pyrometer, originating in observations made as early as 1860, connected his studies in metallurgy and in the science of heat with his electrical researches. During many years past he took a highly prominent part in the application of electricity for lighting, for heating, for transmitting power, and for other important industrial purposes, notably for horticulture and agriculture. At his country residence near Tunbridge Wells, not only did electricity perform much of the actual farm-work, in sawing wood and pumping water, but it was also made to supply in part the place of the sun itself, in assisting the growth of plants, vegetables, and fruits. Another subject that had most recently been engrossing very much of his thought was the conservation of solar energy; and

in 1882 he laid before the Royal Society the remarkable theory which he had been led to adopt as the result of his investigations.

The papers he contributed to the many scientific societies of which he was a member are very numerous. To this Institution alone he communicated no less than thirteen, of which the subjects and dates are as follows:—Regenerative Condenser, 1851; Expansion of Isolated Steam, and Total Heat of Steam, 1852; Pendulum Chronometric Governor, 1853; Screw and Spiral Water-Meters, 1854 and 1856; Regenerative Furnace, 1857; Covering Telegraph Wires with India-rubber, 1860; Regenerative Gas Furnace, 1862; Liquid Chronometric Governor, 1866; Le Chatelier's Counter-pressure Steam Brake, 1869; Steam-Jet for Exhausting Air, 1872; Presidential Address, 1872; High-Pressure Vessels, 1878.

He became a Member of the Institution in 1851, whilst residing at Birmingham, prior to settling in London; and was a Member of Council from 1857, a Vice-President from 1868, and President in 1872 and 1873. His linguistic attainments were very remarkable; accent apart, he spoke purer and more correct English, and with far greater facility of expression, than most Englishmen by birth.

His death took place on 19th November 1883, at the age of sixty, after a short illness consequent upon a fall in walking. He was buried in Kensal Green Cemetery on 26th November, after a funeral service in Westminster Abbey. An address of condolence from the President and Council (see *ante*, p. 8) was presented to Lady Siemens on behalf of the Institution.

JOHN HENRY SOKELL was born on 31st January 1846. In the year 1860, he entered the service of Messrs. Manning Wardle and Co., engineers, Leeds; and in 1867 went to the Hunslet Engine Co., Leeds. In 1873 he became the local representative of the Monk Bridge Iron Co., Leeds, in whose employment he remained until the time of his death, which took place on 17th February 1883. He became an Associate of the Institution in 1882.

THOMAS SAMUEL SPECK was born in London in 1836, and served the usual term of pupilage under Mr. F. H. Trevithick. When Mr.

Trevithick was appointed locomotive and carriage superintendent of the Grand Trunk Railway, Canada, he accompanied his chief, and was placed in charge of the drawing office. He made the drawings of the first locomotive built by the company; and was subsequently engaged in the construction of the carriage and wagon stock, besides being employed as one of the principal assistants in the supervision and working of the western portion of the line, including that part lying in the State of Michigan, U.S. Returning to England in 1860, he became assistant to the late Mr. William Martley, then locomotive and carriage superintendent of the London Chatham and Dover Railway, and was engaged in designing and erecting the rolling stock and shops, and in the general supervision of the works. In 1868 he was appointed locomotive and carriage superintendent of the Scinde Railway; and on the amalgamation of that line with the Punjaub Railway he was offered by the Indian government the only appointment then vacant, that of chief assistant locomotive superintendent on the Bombay Baroda and Central Indian Railway, which however he declined. Leaving India early in 1871, he was appointed resident engineer and locomotive and carriage superintendent of the Metropolitan District Railway, which position he held till June 1881. He died on 3rd November 1883, and was buried on 8th November at Kensal Green. The very large and spontaneous attendance at his funeral, of his late colleagues, and of the men employed under him both on the Metropolitan District Railway and on the London Chatham and Dover Railway, and of numerous private friends, testified to the universal esteem and regard in which he was held by all who knew him. He became a Member of the Institution in 1876.

John Henry Storey was born in Manchester in December 1830. At the age of thirteen he commenced work under his father at the Knott Mill Brass and Copper Works, Little Peter Street, Manchester; and after gaining a practical knowledge of the business, early took the principal part in the management, which position he retained until two years ago, when he was obliged to retire on account of ill-health. His death took place in Manchester on 16th

February 1883, at the age of fifty-two. He became a Member of the Institution in 1863; and in 1871 read a paper on a steam-power meter and continuous indicator, with which he was connected.

RICHARD TAYLOR, born at Holwell near Tavistock on 4th March 1810, was the second son of Mr. John Taylor, at that time managing engineer of Wheal Friendship copper mine and other mines in the Tavistock district. After receiving their education at the Charterhouse School, and at Manchester College, York, he and his elder brother, of whom a memoir is given in the Institution Proceedings 1882, p. 13, acquired much knowledge of practical mining in the mines under their father's management in this country; they subsequently spent nearly the whole of the year 1828 in Germany, visiting the principal mines of the Rhenish provinces, of the Hartz Mountains, of Freiberg in Saxony, and of Hungary, South Austria, and Bavaria. On returning from Germany, he took the management of the Consolidated Mines and the United Mines at Gwennap, Cornwall, and of other mines in that county. He there effected many important practical improvements, especially in the dressing of the ores: for which he first introduced the crusher, for the reduction of the rough ores; soon afterwards the jigging machines, for treating larger quantities and so facilitating and cheapening the cost of dressing; and still later, at Tywarnhayle in 1847, the circular buddle, which, though of minor value in the treatment of copper ores, has since been universally adopted for tin dressing, and found of the greatest value. He also received the appointment of mineral agent to the Duchy of Cornwall, which he held for many years. In 1851 he came to London, and was admitted into partnership with his father and brother in the firm of John Taylor and Sons. In 1853 they took the management of the Linares lead mines in Spain, and soon afterwards became connected with other mines in Spain, Portugal, and France, and subsequently in the colonies; the Cape Copper Mines were started and successfully developed under their direction. In the management of all of these Mr. Richard Taylor took an active part, particularly in the direction of the extensive lead mines and smelting works at Pontgibaud, Puy de Dôme, France, of which he was engineer-in-chief to the end of

his life. He had also a large share in establishing the Couëron lead smelting works and rolling mills on the Loire, which were amalgamated a few years ago with the Pontgibaud establishment. In his management of these French works and of the Panther lead smelting works in Bristol, the close attention which he paid to the condensation of the lead fumes led to great improvements, resulting in a proportionate diminution of the loss by volatilisation. He was specially interested in the successful re-working during the past seven years, under his own management, of the Mellanear copper mine near Hayle, previously known as Wheal Alfred; and he continued to the last to take a warm interest in the mining industries of Cornwall and Devon. He was one of the founders of the Royal Cornwall Polytechnic Society, of which he was honorary secretary for thirty-seven years, and president in 1877 and 1878. He became a Member of the Institution in 1862; and in connection with the summer meeting held in Cornwall in 1873 he took a very prominent part in the discussions upon mining subjects, and in escorting the members in their excursions to the numerous mines and works visited on that occasion (see Proceedings 1873, pp. 87–248). His death took place at his residence in London on 28th December 1883, in the seventy-fourth year of his age, after a few days' illness from an acute attack of bronchitis.

THOMAS WHEATLEY was born at Micklefield near Leeds in 1820, and was early apprenticed for seven years on the Leeds and Selby Railway. He was then employed for several years on the Midland Railway, and afterwards for seventeen years on the Manchester Sheffield and Lincolnshire. He next had charge for five years of the locomotive department on the southern division of the London and North Western Railway; after which he was for eight years locomotive superintendent of the North British Railway. Subsequently he became manager of the Wigtownshire Railway, and had held that position about eight years at the time of his death, which took place on 13th March 1883, in the sixty-third year of his age. He became a Member of the Institution in 1867.

Lamplugh Wickham Wickham was the youngest son of Rev. Lamplugh Hird, of Low Moor House, Bradford, who had exchanged his own paternal surname of Wickham for that of his wife. On his father's death, the son resumed the name of Wickham, claiming descent from two of the bishops of Winchester, William de Wykeham who died in 1404, and William Wickham who died in 1595. For fifty-eight years he was actively engaged in the management of the Low Moor Iron Works; and during that period much of the success of the works was due to his ability, tact, and energy, in carrying forward the practical as well as the commercial part of the business. For many years he was the managing partner of the firm, and retained that position till his death, which took place at his residence at Boston Spa, near Tadcaster, on 2nd January 1883, at the age of seventy-five, after some weeks' illness consequent upon an accident in hunting. He became a Member of the Institution in 1859.

Owen Wright was born at Dudley on 22nd March 1835. On leaving school he entered his father's works; and after a few years was admitted a partner into the firm of Peter Wright and Sons, anvil and vice manufacturers, of Dudley, and of Broadwell Forge and Wire Mills, Oldbury; the business, after his father's death in 1875, was carried on by himself and his brother. He was associated with his father in perfecting and carrying out several improvements in the manufacture of anvils and vices. For the last fifteen years he had the entire management of the works at Oldbury. He died on 20th October 1883, at the age of forty-eight, after only about a week's illness from a severe attack of inflammation of the lungs. He became a Member of the Institution in 1863.

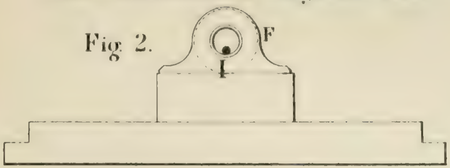
PHYSICAL CONDITION OF IRON AND STEEL.

Plate 1.

Magnetic Balance.

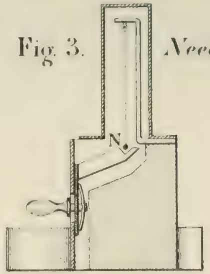
End Elevation of Magnetic Coil.

Fig. 2.



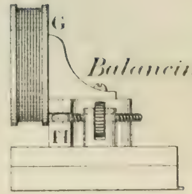
Scale 1/2

Fig. 3. *Needle.*



Scale 1/2

Fig. 4. *Balancing Coil.*



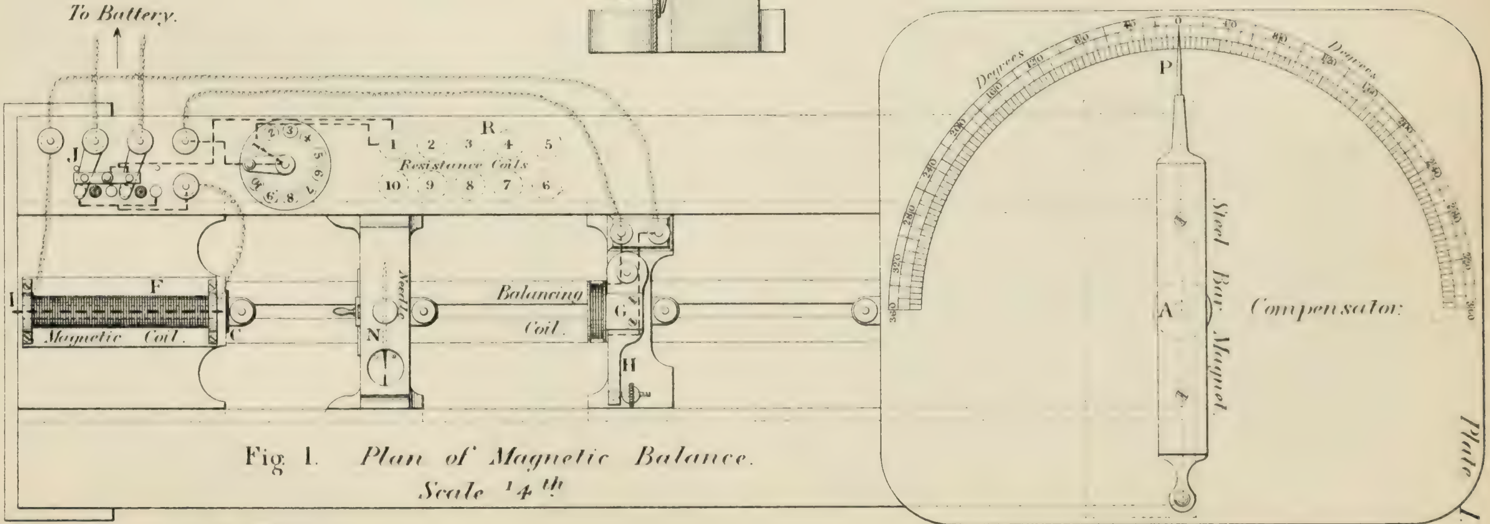


Fig. 1. *Plan of Magnetic Balance.*

Scale 1/4th

Plate 1.

(Proceedings Inst. M. E. 1884.)

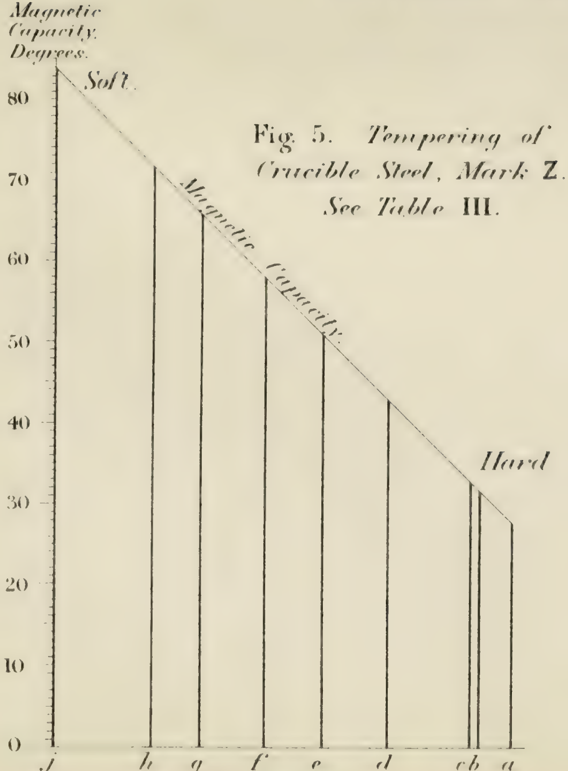


Fig. 5. *Tempering of Crucible Steel, Mark* **Z**. *See Table* III.

(Proceedings Inst. M.E. 1884.)

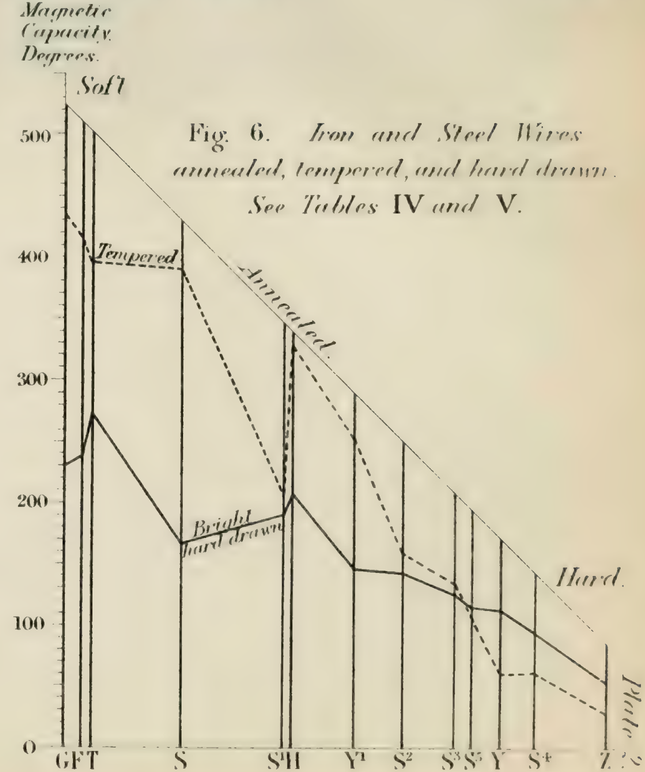
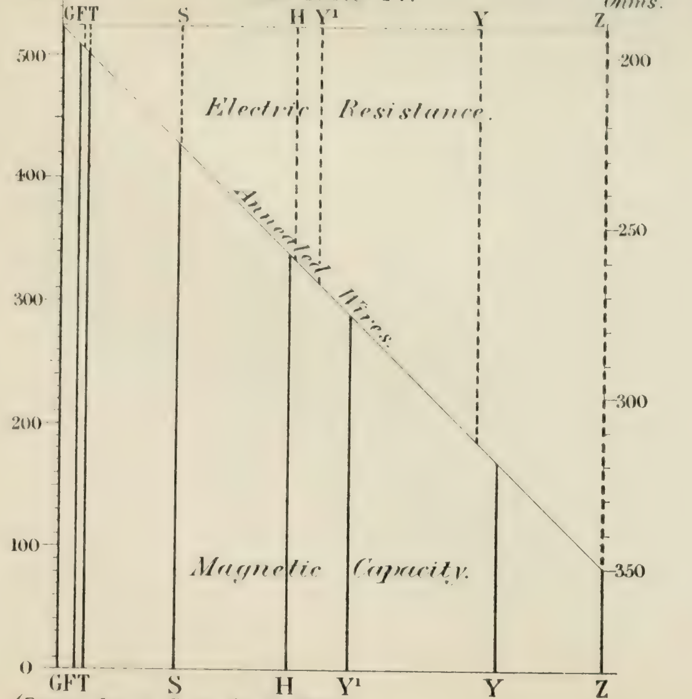


Fig. 6. *Iron and Steel Wires annealed, tempered, and hard drawn. See Tables* **IV** *and* **V**.

PHYSICAL CONDITION OF IRON AND STEEL.

Fig. 7. *Relation between Magnetic Capacity & Electric Resistance.* *See Table* IV.



(Proceedings Inst. M. E. 1884.)

Fig. 8. *Relation between Hardness and Tensile Strength of Annealed Wires.* *See Table* IV.

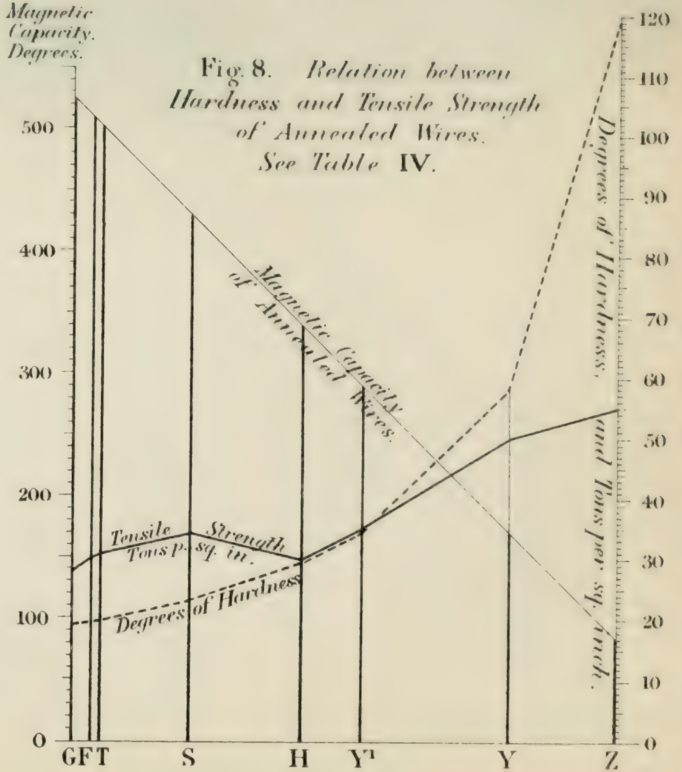


Plate 3.

Institution of Mechanical Engineers.

SPECIAL MEETING

FOR APPOINTMENT OF SECRETARY.

May 1884.

A Special Meeting of *Members* of the Institution was held at the Westminster Palace Hotel, London, on Thursday, 1st May, 1884, at Three o'clock p.m., for the appointment of a Secretary; I. Lowthian Bell, Esq., F.R.S., President, in the chair.

The President explained that the Council had advertised for candidates for the office of Secretary to the Institution, and one hundred and ninety replies had been received. From these applications the names of twelve candidates had been selected; and full particulars respecting their qualifications had been sent to every Member for his consideration. After a personal interview with each of the twelve selected candidates, the Council were now prepared to state their views, if requested by the Members so to do.

Mr. E. Hamer Carbutt, M.P., moved that Mr. Alfred Bache be appointed Secretary of the Institution. He had been connected with the Institution for twenty-nine years, the last fifteen as Assistant-Secretary.

Mr. Charles Markham seconded the motion.

Mr. Alfred Davis moved as an amendment that the Council be asked to state their views.

Mr. John Price seconded the amendment, which, after being supported by Mr. Henry Davey, Mr. William E. Rich, and Mr. Arnold Lupton, was put and carried.

The President stated that the Council recommended three names for the choice of the Members, which had been placed in the following order:—Mr. George C. V. Holmes, who had been for five years Secretary of the Institution of Naval Architects; Mr. G. F. Armstrong; Mr. Alfred Bache.

Mr. Alfred Davis proposed the election of Mr. Holmes, which was seconded by Mr. William E. Rich, and supported by Mr. John Robinson, Mr. Henry Shield, and Mr. Henry Davey. On being put to the Meeting, it was negatived.

Mr. John Robinson proposed the election of Mr. Armstrong, which was seconded by Mr. Charles Cochrane. On being put to the Meeting, it was negatived.

Mr. E. Hamer Carbutt, M.P., proposed the election of Mr. Bache, which was seconded by Mr. Charles Markham, and supported by Sir Frederick Bramwell, Mr. Daniel Adamson, Mr. E. Windsor Richards, Mr. J. McFarlane Gray, and Mr. M. Holroyd Smith. On being put to the Meeting, it was carried.

On the motion of Mr. Arthur Paget, seconded by Sir Frederick Bramwell, a vote of thanks was unanimously passed to the President for his excellent conduct of the Meeting.

The Meeting then terminated.

Institution of Mechanical Engineers.

PROCEEDINGS.

May 1884.

The Spring Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Thursday, 1st May, 1884, at Half-past Seven o'clock p.m.; I. Lowthian Bell, Esq., F.R.S., President, in the chair.

The Minutes of the last Meeting were read, approved, and signed.

The President announced that the Ballot Lists for the election of New Members had been opened by a Committee of the Council, and the following forty-five candidates were found to be duly elected:—

MEMBERS.

Elias Barlow,	Manchester.
Robert Skeffington Boyer,	Cardiff.
Oswald Brown,	London.
Charles Ziethen Bunning,	Warora.
Henry Carrick,	Gateshead.
Charles Cole,	Bowling.
Charles Alexander Crook,	London.
James Young Davidson,	Nagpur.
Paul Decauville,	Petit-Bourg.
John Piggin Fearfield,	Nottingham.
Joseph Petrie Fielden,	Rochdale.
Henry Oakden Fisher,	Cardiff.
Edward Furness,	London.
Arthur James Gimson,	Leicester.
John Ward Girdlestone,	Bristol.

Walter William Goodger, . .	Derby.
James E. Griffiths, ...	Cardiff.
Arthur Henry Hernu, . . .	London.
Matthew Wilson Hervey, . . .	London.
William Thomas Hogg, . . .	London.
Calvert Bernard Holland, . .	Ebbw Vale.
Thomas William Moseley Jacks, .	Wednesbury.
Howard Rudulph Justice, . . .	London.
Henry Watkin Lewis, . . .	Cardiff.
John Lowdon, ...	Cardiff.
Alexander Sinclair Macpherson, .	Leeds.
Augustus John Marquand, . . .	Cardiff.
Robert Monroe, ...	Penarth.
Henry Nicholson, ...	Liverpool.
Walter Elliott Nicholson, . .	Newcastle-on-Tyne.
George Rutherford, ...	Cardiff.
Coleman Sellers, ...	Philadelphia, U.S.
William Shanks, ...	Johnstone.
Sydney Ferris Walker, . . .	Cardiff.
Frederick Peter Wallau, . . .	Belfast.
Richard George Webb, . . .	Motherwell.
Lieut. Harry Borlase Willock, R.E.,	London.
James Wilson, ...	Cairo.
Thomas Wilson, ...	Newcastle-on-Tyne.
Sydney Prescott Wood, . . .	Cardiff.

ASSOCIATE.

William Ripper, ...	Sheffield.

GRADUATES.

Robert Arthur Bell, . . .	Kew.
Harry Bocquet, ...	Fleetwood.
Follett Holt, ...	London.
Mervyn Armytage Streatfeild, . .	London.

The following papers were then read and discussed :—

On the Consumption of Fuel in Locomotives; by M. Georges Marié, of Paris.

On Portable Railways; by M. Paul Decauville, of Petit-Bourg, Paris.

At Ten o'clock the Meeting was adjourned to the following evening.

The Adjourned Meeting of the Institution was held at the Institution of Civil Engineers, London, on Friday, 2nd May, 1884, at Half-past Seven o'clock p.m.; I. Lowthian Bell, Esq., F.R.S., President, in the chair.

The following papers were read and discussed :—

On the Moscrop Engine Recorder, and the Knowles Supplementary Governor; by Mr. Michael Longridge, of Manchester.

Description of the Automatic and Exhaust-Steam Injector; by Mr. A. Slater Savill, of Manchester.

Description of the Apparatus used for Testing Current-Meters, at the Admiralty Works at Torquay for experimenting on models of ships; by Mr. Robert Gordon, of Burmah.

On the motion of Mr. John Robinson, seconded by Mr. Joseph Tomlinson, a vote of thanks was passed by acclamation to the Institution of Civil Engineers, for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated.

ON THE CONSUMPTION OF FUEL IN LOCOMOTIVES.

By M. GEORGES MARIÉ, Engineer of the Paris and Lyons Railway.

During the past twenty years a great advance has been made in regard to Economy of Fuel in steam engines. In marine engines remarkable results have followed from the general use of compound cylinders and surface condensers; for whereas their consumption was formerly from $3\frac{1}{2}$ to $4\frac{1}{2}$ lbs. per I.H.P. per hour, it has now been reduced to about 2 lbs., and sometimes even less.* Equally good results are obtained with Corliss engines. This progress in economy of fuel has led to the endeavour to effect a corresponding reduction in locomotives. But, before the ordinary build of locomotives so long in vogue is abandoned, their exact consumption ought to be ascertained. Generally it is measured in lbs. per mile; but that mode is not a convenient one for comparison, because it takes no account of gradients, weight of train, speed, and train-resistance, all of which are so variable that the bare statement of consumption per mile is of scarcely any value. The only proper way of reckoning the consumption, so as to admit of comparison under different circumstances, is in lbs. per horse-power per hour; and this is accordingly the method described in the present paper, as applied to locomotives under ordinary working conditions.

There is a general impression that locomotives consume as much as from $4\frac{1}{2}$ to $5\frac{1}{2}$ lbs. of fuel per horse-power per hour. With a view to dispel this very prevalent error, the author can quote experiments made by himself during the last few years, which show an average consumption in good locomotives of 3·35 lbs., when the HP. is

* See Paper by Mr. F. C. Marshall, Proceedings 1881, p. 452.

measured by the work done at the circumference of the driving wheels, and of 2·91 lbs., when it is measured by the indicator diagrams; the fuel being of good quality and the firing done with care. Comparing this with the marine-engine consumption of 2 lbs. per I.H.P., it is seen that locomotives are much more economical than is usually supposed, considering that they work non-condensing while marine engines enjoy the great advantage of condensation.

The author's first experiments on this subject, made in 1877 on the line between Rive-de-Gier and St. Étienne in the department of Loire, gave a consumption of 2·90 to 3·24 lbs. per I.H.P. per hour;* other experiments confirming this consumption were also made on a longer length between Alais and Langeac on the Nîmes and Clermont line. These results, which were widely criticised, led M. Hirsch, professor of steam and engineering at the École des Ponts et Chaussées, to request that the experiments might be repeated in his presence. Fresh trials, which may be considered official, were accordingly made with him on 18th, 20th, and 21st of July, 1882, on the Mont Cenis line between St. Jean-de-Maurienne and Modane, with the ordinary trains. The average consumption was again found to be 2·90 lbs. per I.H.P. per hour. In these experiments neither indicator nor dynamometer of any kind was used, such delicate instruments being liable to give rise to errors. Indicators especially occasion considerable errors through the oscillations of the piston-rod and spring, and in general give accurate results only from stationary engines working at slow speeds.

The following are the particulars of the three days' trials, which it is hoped will successfully clear the locomotive from the imputation of wastefulness in consumption of fuel.

18th July, 1882.—Experiment with Anzin Patent Fuel.

Choice of Line.—For experiments of this kind the writer generally chooses a steep rising gradient, because the work performed by the engine can then be easily and accurately calculated. It then consists

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* See "Revue des Chemins de fer," July, 1881, p. 17.

of two portions: first, the work due to the train-resistance on a level; and secondly, that due to gravity on the incline. On a steep rising gradient this latter portion becomes much the more important, while it can always be determined with accuracy, being the product of the total weight of train and engine, multiplied by the difference in level between the two ends of the incline; whereas the calculation of train-resistance on a level is always subject to slight errors, arising from variations in the circumstances of wind and weather. Hence the steeper the incline up which the engine takes the train, the greater is the accuracy with which the work done can be calculated. In this way the engine duty can practically be determined without the use of either indicator or dynamometer of any kind. The portion of line selected for the trials was the length of $17\frac{1}{3}$ miles between St. Jean-de-Maurienne and Modane stations on the Mont Cenis line: the gradients are 1 in 100 to 1 in 35, rising towards Modane, which is 1709 feet above the lower station; the average gradient is 1 in $53\frac{1}{2}$.

Choice of Train.—The train chosen was a passenger train starting from St. Jean-de-Maurienne at 12.21 noon, stopping only once on the way, at St. Michel, for three minutes, and reaching Modane at 1.25 P.M.; the average speed was accordingly 17·40 miles per hour. The engine, built from the designs of the writer's father, the late Ernest Marié, had eight wheels coupled, and its principal dimensions were as follows:—

Cylinders	Diameter		$21\frac{1}{4}$ inches.
	Stroke		26 inches.
Wheels, diameter			4 feet $1\frac{3}{8}$ inches.
Heating Surface	Firebox	104·52	2149·70 sq. ft.
	Tubes	2045·18	
Fire-grate area			22·39 sq. ft.
Boiler pressure			128 lbs. per sq. in.

The weight of the train, ascertained with the greatest care, was 163·58 tons, the particulars of which are given in the Tabular Summary appended (page 92): engine, tender, and carriages were all weighed accurately on weighing machines.

Calculation of Work Done.—If calculated at the circumference of the driving wheels, not in the cylinders, the work done is exclusive of the engine friction, and is given by the simple formula—

$$\text{Work done} = W \times l \times r + W \times h;$$

where W = total weight of train, including engine and tender, = 163·58 tons = 366,419 lbs.; l = distance run = 17·334 miles = 91,536 feet; r = coefficient of resistance, which is taken to be $\frac{1}{232 \cdot 5}$ in the present case, or $9\frac{5}{8}$ lbs. per ton; h = height of train's ascent = 1709 feet. The choice of the coefficient $\frac{1}{232 \cdot 5}$ will be explained further on. Substituting the foregoing values—

$$\text{Work done} = 366{,}400 \times (91{,}536 \times \frac{1}{232 \cdot 5} + 1709)$$
$$= 366{,}400 \times (394 + 1709) = 770{,}600{,}000 \text{ ft.-lbs.}$$

Of this work the portion due to the resistance on a level amounts to only $\frac{394}{394 + 1709}$ or barely one-fifth, while gravity absorbs the remaining four-fifths. Hence an error of as much as 10 per cent. in the coefficient of resistance occasions only 2 per cent. error in the calculation of the work; while even 20 per cent. error in the coefficient causes only 4 per cent. error in the result. Although therefore the coefficient here taken of $\frac{1}{232 \cdot 5}$ may be open to criticism, it is clear that it may be considerably modified without sensibly affecting the calculation of the work done. This constitutes the principle on which the author's trials have been based; whereby he has been enabled to arrive at an accurate determination of the work done, without the use of either indicator or dynamometer of any kind. The sole objection to the method is that it applies only to moderate speeds, inasmuch as high speeds would be dangerous on the curves of a mountain line.

Consumption of Fuel.—To ascertain correctly the consumption of fuel, the author employed a different method from that ordinarily followed in locomotive trials. The general plan is, after lighting the fire and getting up steam, to note the pressure shown by the gauge, and the height of the water-level, and to estimate the quantity of coal then on the grate. The trial is then made, and is so arranged

as to end with the same pressure and water-level as at starting; and the coal remaining on the grate is again estimated. The correct consumption is arrived at by measuring the quantity consumed on the journey, adding what was on the grate at starting, and subtracting what remains at the end. Unfortunately it is impossible to determine correctly the quantity of burning fuel on the grate; and in consequence the calculated consumption almost always involves a serious error. This is one cause of the discrepancies met with in statements of fuel-consumption.

In the author's trials the above source of error has been completely avoided by the following mode of procedure. The engine tried had already made one journey that morning, so that it was in steam, with a pressure of 46 lbs. per sq. in., before lighting the fire for the experimental trip. The water-level was 5·16 inches above the mean line. The fire-grate was cleared of every particle of fuel from the previous journey. The tender was loaded with 1 tonne, or 2205 lbs., of Anzin patent fuel in bricks, and 119 lbs. of wood was served out for lighting the fire. The wood was included as fuel in reckoning the actual consumption, and was taken as equivalent to not more than 44 lbs. of coal; the total supply of coal would therefore be 2249 lbs. Steam was quickly got up, and shortly afterwards the engine was coupled to the train in St. Jean-de-Maurienne station, and proceeded thence up the incline to Modane. The trip was made with the engine working in the ordinary way, with 128 lbs. steam, cut off at 19 per cent. of the stroke. Professor Hirsch, and M. Bazire of the locomotive department, accompanied the author on the engine. The firing was so managed as to have no coal at all left on the grate on reaching Modane. The steam-pressure was then found to be 20 lbs. per sq. in., and the water-level 4·49 inches below the mean: the datum level in the locomotives of the Lyons Railway being not the actual low-water line, but a mean level below which the water may fall without danger. The water-gauge was of course observed while the engine was on the level portion of the line in the station, the line running level through every station on this railway. The coal remaining in the tender weighed 1133 lbs., which would show a consumption of 2249 − 1133 = 1116 lbs., if the boiler

had been in exactly the same state after the trip as before; but no skill could succeed in securing the same steam-pressure and the same water-level as on lighting the fire. A slight correction has therefore to be made in the coal-consumption, to allow for the difference in quantity of heat contained in the boiler before and after the trip.

Correction for difference of Heat in Boiler.—Calculating first the quantity of heat contained in the boiler on lighting the fire, and secondly the heat remaining in it after the trip, the difference converted into lbs. of coal will be the correction to be made in the weighed consumption of 1116 lbs., to give the true consumption.

Firstly, at the time of lighting the fire, when the water-gauge stood at 5·16 inches above datum, the quantity of water in the boiler would be 1571 gallons or 251 cub. ft., as ascertained from the dimensions given in the Tabular Summary appended. The temperature corresponding with the steam-pressure of 46 lbs. is 293° F. The weight of water therefore, allowing for its expansion, would be 14,506 lbs.; and this, at the temperature of 293° F., would contain 3,436,000 heat-units, reckoning from the temperature of the air at the time, which was 59° F. The metal of the boiler, weighing about 20 tons, would contain about 1,175,000 heat-units. The heat in the steam may be neglected. Hence the total quantity of heat contained in the boiler at the time of lighting the fire, above the air temperature of 59° F., would be 4,611,000 units.

Secondly, the heat remaining in the boiler after the trip, estimated in the same manner, would amount to 3,143,000 units.

The difference, or 1,468,000 units, is therefore the additional heat expended during the trip. As the weight of dry steam generated per lb. of coal consumed was found to be 8·08 lbs., and as each lb. of steam at the pressure of 128 lbs. per sq. in. contains 1169 heat-units above the feed-water temperature of 59° F., the boiler would produce in practice $8 \cdot 08 \times 1169 = 9445$ heat-units per lb. of coal. The additional expenditure of 1,468,000 heat-units during the trip is therefore equivalent to 155 lbs. of coal, which,

added to the weighed consumption, gives 1271 lbs. as the true consumption of coal for the trip.

Consumption of Fuel per Effective HP. per Hour.—The work done, corresponding with the above consumption of 1271 lbs., was 770,600,000 ft.-lbs. Hence the coal-consumption per HP. per hour was $\frac{33{,}000 \times 60 \times 1271}{770{,}600{,}000} = 3 \cdot 27$ lbs., the work being the effective work measured at the circumference of the driving wheels.

Throughout the foregoing calculation, the only coefficient open to dispute is that of the train-resistance, which has been taken at $\frac{1}{232 \cdot 5}$; but it has been seen that even a considerable percentage of error in this coefficient would involve no appreciable error in the final result of $3 \cdot 27$ lbs. consumption per effective H.P. per hour. To get at the consumption per indicated H.P., it is only necessary to deduct the proper allowance for the engine friction; which has been found, in careful experiments made by the writer's father, to absorb at least 12 per cent. of the indicated power, when the engine is in perfect working order. Hence the corresponding consumption per indicated H.P. per hour would be $3 \cdot 27 \times \frac{100-12}{100} = 2 \cdot 88$ lbs. as a maximum.

Consumption of Water and production of Dry Steam. — The consumption of water on the trip, from the tender and from the boiler, was measured with the greatest care, allowing for expansion of the water in the boiler. It was found to amount to 11,290 lbs., or $8 \cdot 88$ lbs. per lb. of fuel. Deducting 9 per cent. for priming, the weight of dry steam produced would be $8 \cdot 08$ lbs. per lb. of fuel.

Nature of Fuel.—Samples carefully analysed of the Anzin patent fuel, which was used in the trip, showed $6 \cdot 9$ per cent. of ash, and 1 per cent. of moisture. The heating power was found to be 14,600 units per lb. It was ascertained by means of apparatus specially made for the purpose, similar to that used by Ebelmen, Fabre, Silbermann, and Berthelot, in their experiments on the heating power

of fuel. It consists of a glass phial, within which a powdered sample of the fuel, placed in a crucible, is burnt in a current of oxygen; the phial is immersed in a measured quantity of water, and the rise of temperature in the water indicates the heat developed by the combustion of the sample. Cardiff coal was tried in the same way by the author, and gave the same heating power; a direct comparison can therefore be made between this experimental trip and any English trials with Cardiff coal. The Anzin patent fuel is in fact composed of 91 per cent. of slack, of the same quality as Cardiff coal, and 9 per cent. of coal pitch, the heating power of which has been found by the writer to be equal to that of ordinary coal.

Remarks.—During the experiment, the admission of steam to the cylinders was for 19 per cent. of the stroke, the clearance spaces being included. The valve gear was tested by Professor Hirsch himself. The locomotive had not been repaired for a long time.

It may be objected that the driver probably looked after the fire much more carefully than usual, being stimulated by the presence of the engineers. This may be, but on the other hand the following circumstances were unfavourable to economy of fuel:—

1. During the firing up, the locomotive gave out some heat to the atmosphere as usual; this loss of heat was equivalent to about 29 lbs. of fuel, according to an experiment made for that special purpose.

2. During the last few minutes of the trial, the engine was running with a very low pressure, in order to arrive at Modane without any fuel on the fire-grate; hence the engine was working during these minutes in unfavourable circumstances.

Experiments made on 20th and 21st July, 1882.

The author, with Professor Hirsch, made two other experiments of the same kind as the first; on the 20th July with patent fuel from Grand' Combe in the Gard coalfield, and on the 21st July with patent fuel from La Chazotte in the Loire coalfield. The results were almost exactly the same as before. A Tabular Summary of the three

experiments is appended (p. 92), in which all the figures may be seen at a glance. The experiments were all made with the same driver, the same engine, and the same kind of train. It will be noted that they were made in the middle of summer. In winter the consumption of fuel is about 10 to 15 per cent. higher, on account of the loss of heat to the atmosphere. The author considers that this loss might be diminished if the boiler were better cleaded—a point which assuredly is susceptible of improvement, especially for cold countries.

Conclusions.

The author has shown that with a good locomotive and a good driver the consumption of fuel and water is as follows:—

Consumption of fuel per effective HP. per hour . .	3·27 lbs.
Consumption of fuel per indicated HP. per hour . .	2·88 lbs.
Ratio of consumption of water to consumption of fuel .	8·88 to 1.
Ratio of dry steam produced to fuel consumed . .	8·08 to 1.

Professor Hirsch attributes these satisfactory results to the following causes:—

1. The total heating surface of the boiler is very large compared with the grate-surface (96 to 1); so that the boiler absorbs the heat of the gases very completely.

2. The cylinders of the locomotive are very large (according to the late M. Marié's system); so that the grade of expansion is high.

3. The locomotive was very well looked after, which is an important point in economy of fuel.

The author may also refer to some experiments made by M. Regray, chief engineer of the Eastern Railway of France: they were made with an indicator on a new system, giving diagrams at the highest speeds, without the errors of the ordinary indicator. The diagrams are taken at some distance from the locomotive itself; the indicator is in a special van, with several dynamometers, speed indicators, &c. This van was shown at the Electric Exhibition in

Paris, and obtained one of the highest prizes. M. Regray made a few experiments on consumption of fuel in express engines with express trains; the result was 3·01 lbs. per I.H.P. as an average, and 2·48 lbs. as the minimum. This is a very satisfactory verification of the author's result of 2·88 lbs. per I.H.P. It is important to notice that these very close results have been arrived at by two methods as different as could be. The fuel employed in M. Regray's experiments was not patent fuel, but ordinary small coal from Bascoup in Belgium.

These satisfactory results confirm what the author's father always maintained, namely that locomotives ought to have large heating surface and large cylinders; he always built his own locomotives by that rule.

The author has thus endeavoured to prove that locomotives are not so imperfect as is generally believed in regard to economy of fuel. Assuredly the locomotive is a very simple form of engine; but simplicity is of great importance with the very high piston-speed of locomotives. High piston-speed however is very favourable to economy in fuel (contrary to the opinion of some engineers), because it diminishes the leakage of steam and the condensation of steam during admission. A locomotive working with a very slow piston-speed is not so economical as with a high speed. Express engines give better results than mountain engines, as is seen by M. Regray's experiments, where the consumption attained the very low figure of 2·48 lbs. per I.H.P. under the best circumstances.

The author has no intention of implying that locomotives will not be improved—in fact he proposes to indicate the probable directions of improvement; but, before abandoning the ordinary system, he thought it would be interesting to make exact experiments, giving the consumption of fuel per HP. Comparative tests with the various kinds of new locomotives ought to be made, and with the same accuracy. Unfortunately different drivers, working under the same circumstances, and with the same kind of locomotive, show consumptions of fuel varying by from 10 to 20 per cent., according to their skill; this is a serious difficulty in making such comparisons between various kinds of locomotives.

TABULAR SUMMARY OF EXPERIMENTS.

ITEMS OF EXPERIMENTS.	Units.	18 July. Patent fuel: Anzin.	20 July. Patent fuel: Grand' Combe.	21 July. Patent fuel: La Chazotte.
Total distance run by train	feet	91,536	91,540	91,540
Ratio of resistance on level to weight of train	ratio	$\frac{1}{232 \cdot 5}$	$\frac{1}{232 \cdot 5}$	$\frac{1}{232 \cdot 5}$
Difference of level of the two stations	feet	1,709	1,709	1,709
Weight of engine and tender (not loaded)	lbs.	125,076	125,076	125,076
" of carriages and vans (not loaded)	lbs.	204,800	225,285	176,212
" of the load on engine and tender	lbs.	24,614	24,738	26,422
" of passengers and men	lbs.	7,409	5,711	4,785
" of goods...	lbs.	4,575	4,264	3,149
Total weight of train	lbs.	366,474	385,074	335,644

Before firing the boiler at Saint Jean-de-Maurienne.	Patent fuel and fagots loaded on tender	lbs.	2,249	2,251	2,249
	Pressure in boiler (above atmospheric pressure) ...	lbs. per sq. in.	46·28	21·36	18·23
	Height of water in boiler (above water-line) ...	inches	+ 5·16	+ 5·24	+ 5·08
After arrival at Modane.	Fuel remaining on tender	lbs.	1,133	966	1,158
	Pressure in boiler (above atmospheric pressure) ...	lbs. per sq. in.	19·65	21·36	7·83
	Height of water in boiler (above or under water-line)	inches	− 4·49	+ 0·82	− 4·73
	Depth of water withdrawn from tanks during the experiment	inches	19·38	27·30	17·38
Weight of metal in boiler		lbs.	44,100	44,100	44,100
Capacity of boiler, water being at water-line		cubic feet	217·4	217·4	217·4
Diameter of cylindrical shell		feet	4·92	4·92	4·92
Total length of boiler		feet	22·31	22·31	22·31
Distance from water-line to top of boiler		foot	0·984	0·984	0·984
Horizontal surface of tanks in tender		square feet	73·59	73·59	73·59

TABULAR SUMMARY OF EXPERIMENTS—(*continued*).

Items of Results.		Units.	18 July. — Patent fuel: Anzin.	20 July. — Patent fuel: Grand' Combe.	21 July. — Patent fuel: La Chazotte.
Work of locomotive measured at circumference of driving-wheels...		foot-lbs.	770,600,000	810,100,000	705,900,000
Apparent consumption of fuel...		lbs.	1,116	1,286	1,094
Before firing the boiler at Saint Jean-de-Maurienne.	Volume of water in boiler	cubic feet	251·34	252·04	250·98
	Temperature of water in boiler	degrees Fahr.	293°	261°	255°
	Weight of water in boiler	lbs.	14,509	14,663	14,652
	Units of heat in water	British units	3,436,000	2,985,000	2,901,000
	Units of heat in metal	British units	1,175,000	1,012,000	988,000
	Units of heat in boiler, total...	British units	4,611,000	3,997,000	3,889,000

After arrival at Modane.	Volume of water in boiler	cubic feet	182·40	223·41	180·64
	Temperature of water in boiler	degrees Fahr.	257°	261°	232°
	Weight of water in boiler	lbs.	10,637	13,031	10,703
	Units of heat in water...	British units	2,135,000	2,652,000	1,885,000
	Units of heat in metal	British units	1,008,000	1,024,000	885,000
	Units of heat in boiler, total...	British units	3,143,000	3,676,000	2,770,000
Loss in units of heat		British units	1,468,000	321,000	1.119,000
Corresponding weight of fuel		lbs.	155	33	123
True consumption of fuel		lbs.	1,271	1,319	1,217
Consumption of fuel per effective HP. per hour		lbs.	3·27	3·22	3·40
Consumption of fuel per indicated HP. per hour		lbs.	2·88	2·84	2·99
Weight of water lost by tender		lbs.	7,420	10,449	6,650
Weight of water lost by boiler		lbs.	3,872	1,632	3,949
Total consumption of water		lbs.	11,290	12,081	10,599
Do. per lb. of fuel		lbs.	8·88	9·15	8·68
Weight of dry steam per lb. of fuel		lbs.	8·08	8·32	7·90
Ash in fuel		per cent.	6·90	9·70	9·60
Moisture in fuel		per cent.	1·00	1·30	1·10
Calorific power of fuel...		British units	14,600	14,400	13,700

Comparison of Practical Results as to Consumption with Theoretical Results.

The author will now compare the practical results in consumption of fuel with the theoretical results given by thermodynamics. This will give the measure of the improvement which remains to be made as regards economy of fuel.

Efficiency of Boiler.—It has been seen that the boiler gives 8·08 lbs. of dry steam for 1 lb. of coal, at 128 lbs. per sq. in. pressure. Now 1 lb. of water at 59° Fahr. requires 1169 units of heat to make 1 lb. of dry steam at 128 lbs. pressure; thus the boiler absorbs $8 \cdot 08 \times 1169 = 9445$ units of heat for each lb. of fuel, whose calorific power is 14,600 units as stated above.

The efficiency of the boiler is therefore $\frac{9445}{14,600} = 65$ per cent. That is to say, the boiler utilises in practice 65 per cent. of the heat given out by the combustion of the fuel; and loses $100 - 65 = 35$ per cent. This loss is due to the following causes:—

1. Loss of heat contained in the gases escaping at the chimney.
2. Loss of heat by conduction to the atmosphere.
3. Loss of heat by the presence of air slightly in excess of that needed for combustion.
4. Loss of heat by the escape of a small proportion of carbonic oxide, not burnt into carbonic acid.
5. Several minor causes.

It is remarkable that the total loss of heat should be only 35 per cent. with so many causes of waste.

One of the best improvements that can be applied to locomotives is the heating of the feed-water with the exhaust steam. Several kinds of apparatus have been designed for that purpose; none of them have been a practical success, but the author hopes the want will be supplied before long.

Efficiency of the Locomotive (Boiler and Engine together).—The quantity of work which a steam engine can theoretically give out

for one unit of heat * depends—

1. On the temperature corresponding to the boiler pressure.

2. On the temperature of the condenser.

The maximum of work in ft.-lbs. given by one unit of heat is:

$$772 \times \frac{T_1 - T_2}{T_1 + 461 \cdot 2}.$$

Here 772 ft.-lbs. is the mechanical equivalent of heat;

T_1 is the temperature Fahr. corresponding to the boiler pressure;

T_2 is the temperature Fahr. of the condenser, which, in steam engines without condensation, is the temperature of boiling water;

461·2 is the number of degrees below Fahr. zero of the absolute zero of thermodynamics.

Applied to the present case of the locomotive, the formula gives:

$$772 \times \frac{356 - 212}{356 + 461 \cdot 2} = 136.$$

That is to say, under such conditions, a theoretical locomotive would give 136 ft.-lbs. of work for one unit of heat. In practice the locomotive gives 1 I.H.P. per hour, or 1,980,000 ft.-lbs., for 2·88 lbs. of fuel, yielding $2 \cdot 88 \times 14,600 = 42,450$ units of heat. Thus the boiler and engine together give practically $\frac{1,980,000}{42,450} = 46 \cdot 6$ ft.-lbs. for one unit of heat. The efficiency of the locomotive (boiler and engine) is therefore $\frac{46 \cdot 6}{136} = 35$ per cent.

Efficiency of Engine alone.—The efficiency of the engine alone is clearly equal to $\frac{35}{65} = 54$ per cent. That is to say, the mechanism of the locomotive, receiving steam and giving out work, gives 54 per cent. of the work which a theoretically perfect engine should give under the same circumstances. The loss of work is $100 - 54 = 46$ per cent. This is due to the following causes:—

* See "A Manual of the Steam Engine and other Prime Movers," by W. J. Macquorn Rankine: London, 1876, p. 343.

1. Loss of work from the expansion of steam in the cylinders not being quite complete.

2. Throttling of the steam, on entering or leaving the cylinders.

3. Back-pressure of the steam during the return stroke.

4. Imperfection of the valve motion.

5. Condensation of steam during admission.

6. Leakages of steam, and several minor causes.

Such are the many causes of loss of work in the engine proper. The resulting efficiency of 54 per cent. is not so good as the boiler efficiency of 65 per cent.; still a loss of 46 per cent. is not very remarkable where so many causes contribute to produce it.

Comparison with a Corliss Engine.—The author made a similar investigation with reference to a boiler and engine on the Corliss system, with condensation. The power was measured by an indicator; the consumption of fuel was also measured, and the results were as follows:—

Pressure in boiler, 5·5 atmospheres. Temperature, 313° F.

Pressure in condenser, 0·9 atmosphere. Temperature, 111° F.

Consumption of fuel per I.H.P., 2·01 lbs. per hour.

Ratio of dry steam evaporated to fuel consumed, 8·5 to 1.

Calorific power of fuel, 14,500.

The efficiency of the boiler and of the engine, compared with the theoretical results of thermodynamics, has been calculated, with the following results:—

Efficiency of boiler, 64 per cent.

Efficiency of mechanism alone, 53 per cent.

These results are almost exactly the same as with locomotives, which give, as we have seen:

Efficiency of boiler, 65 per cent.

Efficiency of mechanism, 54 per cent.

That is to say, the locomotive, compared with a theoretically perfect locomotive, is quite as good as a Corliss condensing engine compared with a theoretically perfect engine working as a Corliss engine.

The author concludes that the locomotive is not so bad as is generally believed in regard to economy of fuel.

The general conclusion is that locomotives are not capable of much improvement as regards economy of fuel, unless the pressure in the boiler can be increased. When the improvements in material and construction will allow the use of higher pressures, then a notable economy will be easily obtained, in proportion to the increase in the value of the expression $\frac{T_1 - T_2}{T_1 + 461 \cdot 2}$ already given for the theoretical maximum work.

But in that case the author considers it will be necessary to employ compound cylinders or more complicated valve-gear, in order to obtain the best utilisation and highest expansion of the steam.

In concluding this paper, he wishes to add his tribute of admiration to those English engineers who have done so much for the existence and improvement of railways. To George Stephenson we owe the locomotive in its present form, the excellence of which, as regards economy of fuel, is still worthy of admiration: while another eminent English engineer, Mr. Webb, is now carrying out a remarkable series of experiments with the view of bringing it to its greatest possible degree of perfection. Having received from Mr. Webb himself details of his compound locomotive, which he has also had the pleasure of seeing at Crewe, the author is led to add here the few observations that have occurred to him in regard to this new kind of locomotive.

If the boiler pressure be not higher than in ordinary locomotives, the author thinks the economy of fuel cannot be greater in the compound engine than in the best ordinary locomotives. With the ordinary boiler-pressure of 128 lbs. per sq. inch, the ordinary valve-gear gives expansion enough, provided the cylinders be large enough, which is not always the case. The compound system lessens the injurious effect of the clearance spaces, and also diminishes the condensation of the steam during admission: but these two advantages

are neutralised by the disadvantage of the steam being throttled in its passage from the first cylinder to the second, especially at high speeds. In other words, the consumption of fuel in a compound engine could not in the author's opinion be much lower than that given in the present paper, the boiler-pressure being the same. This point would be readily settled by a few experiments on the consumption of fuel per horse-power per hour in the compound locomotive, including lighting up. The particular locomotives of ordinary class, with which the compound engine has been compared by Mr. Webb, appear to the author to be somewhat too heavily loaded for the best economy, their cylinders being smaller than those of the express locomotives on the Paris and Lyons Railway, which have cylinders of 19·7 ins. diameter and 24·4 ins. stroke, with 6 ft. 6 ins. driving wheels. Fuel being very expensive on this line, the author's father always made his engines heavy but very economical; and these express engines, which were designed by him and built at the works of the Paris and Lyons Railway and of Messrs. Sharp Stewart and Co., are some of the most economical locomotives there are. The author has indeed made experiments in which, on the same kind of line, and at the same speed, and with the same total weight of train, the consumption of fuel was almost exactly the same as in the latest experiments with the compound locomotive; but he cannot look upon such a comparison as of great value, because it is impossible to estimate precisely the difference of circumstances in the two cases. The further experiments he has suggested with the compound engine seem therefore to be needed for a fair comparison.

In his own experiments the author has found 128 lbs. per sq. inch to be the maximum boiler-pressure for obtaining good expansion with ordinary valve-gear and with cylinders of ordinary size. With higher pressures, either better valve-gear must be employed, or the compound system; and the latter is considered decidedly preferable by the author, who has shown that great economy of fuel can be obtained with a high boiler-pressure. In Mr. Webb's compound locomotive the boiler is both so strong and so light that the author considers the pressure of steam can be increased without making

the engine too heavy for the rails. It will then be a necessity to adopt the compound system for obtaining good expansion; and Mr. Webb's compound locomotive, without being too heavy, will then unquestionably be much more economical than ordinary engines could be, and will be well adapted for high speeds. Goods engines of the ordinary kind are not so economical in consumption per horse-power per hour as express engines; and the author anticipates therefore even better results from the compound system in goods engines than have been obtained with express locomotives. The compound system, with yet higher boiler-pressure, will thus in his opinion turn out to be the greatest improvement in locomotives since the time of Stephenson.

Discussion.

Mr. Alexander McDonnell said it was extremely gratifying to find a set of experiments carried out with the amount of care that had evidently been bestowed upon those described in the paper just read. One of the faults which locomotive engineers in this country had committed was that many of their results had been arrived at rather carelessly, not with such an amount of care as those described in the paper had evidently received. It was certainly very difficult to carry out experiments of that sort with extreme care. The heavy traffic on some railways rendered it impossible to make use of the line for several hours in order to carry out careful experiments and obtain accurate results. Besides that, there were many locomotive engineers who had hardly got time to make such experiments at all.

With regard to Mr. Webb's compound locomotive, he was greatly inclined to agree with a good deal of what had been said in the paper; and he should certainly expect very much better results

from a compound goods engine than from the passenger engine upon which Mr. Webb had made his first trial of the compound system. Of course the compound arrangement was simpler for a passenger engine than for a goods engine; there were several points about the goods engine, the coupling of the wheels and so on, which rendered the application of the compound plan less simple than to a passenger engine. But the very fact of the passenger engine having to work much more uniform loads, while a goods engine was working sometimes with nothing but two or three wagons and at other times with fifty or sixty, would naturally lead to the expectation that the goods engine would give more satisfactory results than the passenger engine, when worked on the compound system.

There were several points in the paper which he thought were exceedingly valuable, and deserving of great consideration; but he should not like to commit himself to a close criticism, particularly when the experiments had been conducted with such a vast amount of care.

The President said there was one gentleman present whom he was sure the Members would be very glad to hear on this subject, namely their Past-President, Mr. Ramsbottom.

Mr. John Ramsbottom said that as regarded compound locomotive engines he had really had no experience whatever. He was very well satisfied with the paper as being a very clear exposition of the character and peculiarities of the locomotive boiler as a steam generator; and it must be satisfactory to engineers generally to learn that that class of boiler showed such good results. He was not surprised to find the writer coming to the conclusion that, in order that the system of working compound upon railways might show a marked advantage over the ordinary system of locomotives, it would be necessary to increase the steam pressure very considerably beyond what was now used. It appeared from the author's views to be pretty nearly a tie, as between the best ordinary locomotive and the compound locomotive working at the same initial pressure. The question therefore resolved itself to his mind into one of producing

a boiler which would generate steam of a higher pressure. It could readily be understood why the introduction of the compound system had led to such remarkably satisfactory results when applied to steam navigation, because in that case it was well known that the boiler pressure had been increased from he supposed 20 or 30 lbs. to 80 or 90 lbs. per sq. in., thereby increasing the range of temperature over which the action of the steam was taken. But locomotive boilers had habitually been carrying 120 to 140 lbs. already, and he supposed they had not got much beyond that; so that the problem in his opinion for engineers to meet was, how to produce a boiler which should generate that higher pressure of steam which was necessary in order to show the advantages of the compound system when applied to railway working.

Mr. JOHN ROBINSON wished he had some knowledge of what was going on with regard to the compound engine; but he was led rather to compare some of the figures given by the author with those given by others. He agreed with Mr. Ramsbottom that they should congratulate themselves upon the results already obtained; and he would call attention to the paragraph in page 99 of the paper, in which the writer came to the general conclusion that locomotives were not capable of much improvement as regarded economy of fuel. He gathered from the rest of the paper that the author's great object in the improvement of the locomotive was simply economy of fuel, because the great question for scientific consideration was economy of fuel in consequence of the greater expense of fuel in France than in England. Then the author seemed to hesitate as to whether that economy could be produced by a change of mechanism or by an increased pressure. On page 100 it was remarked that in the compound locomotive the boiler was both strong and light. Mr. Ramsbottom, who had just spoken, had been looked upon at the time when he was ruling the locomotive department of the London and North Western Railway as an advocate for a rather light boiler; and he regretted the author was prevented from being present to explain how Mr. Webb had succeeded in obtaining a light boiler which was so strong. The author's object appeared to be to

get a higher initial pressure in the boiler than was usual in France; he seemed to say that the economy in fuel which he had in view might be found, either by increasing considerably the pressure of the boiler, probably to 150 lbs. initial pressure or even more, or else by the use of a compound engine such as that referred to.

Another regret which every one in the meeting would share was that Mr. Webb was not present, in order to show what was the economy which Mr. Webb himself considered that he had already obtained with compound engines working on the London and North Western Railway; that economy he believed, and doubtless Mr. Tomlinson would say the same, had reached something like one-fourth the total consumption of fuel. As to what was said in the paper with regard to the care that an engine driver would give to his engine in the presence of engineers watching the result of their experiments, the same remark might to some extent be applied to every engine driver, especially on the railway of the engineer who was the inventor of the engine. But still, with all that allowance, he believed Mr. Webb had an impression on his own mind, and had succeeded in conveying it to the minds of others, that the economy which he had obtained in the compound passenger engines had been very considerable, to the extent of something like 25 per cent. of the total consumption of fuel. Since Mr. McDonnell's view also coincided with that of the writer of the paper, that the saving would be still greater in goods engines, he thought there was a very hopeful future for the locomotive; and, in contrast with the statement made on page 99 of the paper, he believed that the locomotive was capable of considerable improvement as regarded the consumption of fuel. They were very much obliged to the author for having furnished in the paper a basis from which to calculate further progress; and the greatest advantage they could derive would be to have a paper from Mr. Webb, giving the results of his trials with compound locomotives on the same basis. They would then see whether the improvement claimed for the compound engine was not a very considerable improvement, exceeding what was looked to in the present paper as the result likely to be obtained in locomotive engines.

Mr. Joseph Tomlinson believed it was admitted that the locomotive boiler was about the best boiler as a generator of steam. But in regard to carrying a higher pressure than at present, it was just a question whether they might not buy gold too dear. Many years ago he had himself tried an experiment of carrying steam at 160 lbs. pressure per sq. in., in comparison with engines working at the regular pressure of 140 lbs.; and he had found the reparation of pistons and valves alone was pretty nearly worth the saving of the coal. He must take some exception to what Mr. McDonnell had said, because in his own opinion the great secret of success in compound engines was high speed of piston, which with a goods engine was hardly obtainable. He believed Mr. Webb's success with his compound engines was simply due to his running them on fast trains. But he thought that for such duty as had to be performed by his own engines on the Metropolitan Railway—running from the Mansion House to Victoria, making six stops and starts, and travelling about $2\frac{3}{4}$ miles in 12 minutes—the compound engine would signally fail, because it would never be able to get the speed up to do the work required. The necessary speed of starting could not possibly be got out of the 13-inch cylinders with which the start had really to be made. With a low-pressure cylinder having only one crank it would be perpetually stopping on dead centres, and would be of no value; and in consequence of stopping six times in twelve minutes the steam would be on the cylinder not more than six minutes, so that the low-pressure cylinder would be a great condenser and not a help.

Then again he took exception to the economy of 25 per cent. obtained with the compound locomotive. No doubt the engine really did produce the 25 per cent. economy as the ordinary result of its working; but it must be borne in mind that this was due to nursing. The greatest possible care had been taken, and everybody connected with the engine had been trying to do the best they could. He himself could not make out 25 per cent. economy in fuel as at all possible in compound locomotives, unless they were also made into condensing engines; therefore he thought the 25 per cent. must be considerably discounted. Then again, if a maximum of 17 to 18 per cent. economy was what could be got out of the compound locomotive

on a long run when worked fairly, the maximum saving would be 6·12 lbs. of coal per train-mile on the Metropolitan Railway, where the present engines were burning 34 lbs. of coal per train-mile, and the coal cost about $9\frac{1}{2}d.$ per cwt., which would give a saving of about $0·52d.$ per train-mile. A saving of 6·12 lbs. of coal upon 34 lbs. could, he thought, be purchased too dear. It must be borne in mind that in the compound locomotive there were three cylinders to maintain, three sets of pistons, three connecting-rods, and three sets of valves: in fact three engines to maintain, instead of two. On the other hand the coupling-rods were done away with, which was of course a very great improvement. On the Metropolitan Railway he found the coupling-rods had only five years' life at best, and they began to crack in a most marvellous manner, and then all of a sudden gave way; therefore to get rid of the coupling-rods would be a great advantage. But on his own line he did not think it would be possible to get the trains along without coupling-rods, unless by using very much larger cylinders than in Mr. Webb's compound engine. If the pressure of steam were to be increased to 160 or 170 lbs. per sq. in., the boilers would not last so long; and therefore their shorter duration would have to be set off against the saving in coal. Another thing was that with a higher pressure of steam the glands would be very difficult to maintain; but still he hoped some day a packing would be invented that would last. He had tried a great many packings himself—metallic, hemp, flax, and all other substitutes; but he never yet had found a perfect packing.

Mr. Druitt Halpin considered this was a most valuable paper, giving exact experiments of what M. Marié had done. The first general statement made in it (page 82) was that locomotives generally were supposed to consume from $4\frac{1}{2}$ to $5\frac{1}{2}$ lbs. of coal per horse-power per hour. In making that statement the author must have overlooked the very elaborate experiments made by Bauschinger about twelve years ago, which showed that the average consumption of the whole of the engines on the Bavarian State Railways was only 27 lbs. of water per horse-power per hour; and taking an evaporation of 8 or $8\frac{1}{2}$ lbs. of water per lb. of coal, which was reasonable, this would bring the coal

consumption down to about 3 lbs. per horse-power per hour, thus already giving the considerable economy of 33 per cent. over what was stated in the paper.

The next statement with which he could hardly agree was on page 83, where the author said that such delicate instruments as indicators and dynamometers were liable to give rise to errors, and that indicators especially occasioned considerable errors through the oscillations of the piston-rod and spring. That was of course true to a certain extent, but only to a limited extent. There were indicators now made from which most remarkable results could be got. There was the Crosby indicator now introduced from America into this country, from which he had himself seen most beautiful diagrams taken at 614 revolutions per minute: which was far beyond any speed the locomotive could want. There was also a still better apparatus, the Boys power meter, which he had lately tested at Crewe, applied to a large rolling-mill engine, and which was like a gas-meter in giving the accumulated actual work that the engine did. The measurement of the power did not depend upon one diagram, or upon any reasonable number of diagrams that could be taken in a certain time. It was simply obtained by taking a reading at a certain time and again at any other time, and, as in a gas-meter, the difference gave the number of foot-lbs. of work that had been done. Whether that instrument was at present in its most perfect state for locomotives he did not profess to say; but he thought it was an instrument that should be used, and for the following very good reasons. In page 88 of the paper it was stated that the author's father had found by experiment that his engines absorbed 12 per cent. of the indicated power in friction: and in page 90 reference was also made to the experiments conducted by M. Regray on the Eastern Railway of France, which were certainly most valuable, particularly on this point, because the indicating tackle there employed was perhaps the most complete, taken altogether, that had ever been used. The special van mentioned in the paper had been placed next the engine, and was fitted with dynamometers to give the exact traction, and with electric indicators by which as many diagrams as were wanted could be taken

with great safety and ease. In a paper read before one of the French societies, M. Regray had given the results of nine experiments on two engines: in the one case the friction of the mechanism alone, apart from drawing the engine and tender, was 34·2 per cent., and in the other case 35·6 per cent. of the total power developed in the cylinders. The net power available at the draw-bar of the tender was found to be only some 45 per cent., by which of course the total work of drawing the train had to be done. Taking this into consideration, he thought the opinion of M. Marié as to indicators not being necessary for such experiments might lead to very false results.

The total economy of the engine, to which the author referred on pages 86–7, where he dealt with the consumption of fuel, was of course a combined question of boiler efficiency in producing the steam and of engine efficiency in using it. Taking the boiler first, he thought if its performance were analysed the locomotive boiler would be found to be certainly without exception the most economical boiler in all respects, both as to economy of evaporation and as to speed of evaporation. The accompanying Table which he had drawn up showed results which were perfectly unexpected by himself. He had here reduced the speed of evaporation in every case to a uniform standard, and also the economy of evaporation; and the examples he had taken included several of the portable-engine boilers at the Cardiff show of the Royal Agricultural Society, a number of Lancashire boilers of which Mr. Mair had kindly given him the particulars, and the boiler of Mr. Webb's compound locomotive; also some standard boilers referred to in Mr. D. K. Clark's works, which burnt coke; and the torpedo-boat boilers. It was seen that the evaporation ranged from 1·52 lbs. of water per square foot of heating surface per hour in one of the portable-engine boilers at Cardiff, up to 20·74 lbs. in a torpedo-boat boiler, showing an enormous difference in rapidity of evaporation. The economy of evaporation from and at 212° ranged from 7·04 lbs. of water per lb. of fuel in the torpedo-boat boiler which was working hardest, up to 12·83 lbs. in the Lancashire boiler which was evaporating at the rate of 1·57 lbs. per square foot of heating

surface per hour. The Table also gave the number of thermal units transmitted per hour per square foot of heating surface from the

No.	Description of Boiler.		Water evaporated from and at 212°. Per square foot of heating surface per hour. A	Water evaporated from and at 212°. Per lb. of fuel. B	Thermal Units. Units transferred per square foot of heating surface per hour. C	Thermal Units. Units transferred per lb. of fuel. D	Thermal Units. Total Units in fuel. E	Percentage of Thermal Efficiency. F	Figure of Merit. C × F
			Lbs.	Lbs.	Units.	Units.	Units.	%	
1	Field		4·57	8·83	4414	8529	..	..	..
2	,, ...		2·28	10·83	2202	10461	..	..	..
3	,, ...		2·57	10·93	2482	10558	..	..	..
4	Portable	Cardiff.	1·52	10·23	1468	9882	14718	67	98356
5	,,	Cardiff.	2·26	10·49	2183	10133	14718	68	148444
6	,,	Cardiff.	1·76	11·81	1700	11408	14718	77	130900
7	,,	Cardiff.	3·56	9·93	3438	9592	..	..	..
8	Lancashire . .		1·57	12·83	1516	12393	15715	78	118248
9	,, . .		2·83	9·89	2733	9553	13833	68	185844
10	,, . .		1·88	12·25	1816	11833	15715	75	136200
11	,, . .		2·57	10·99	2482	10529	15715	67	166294
12	Compound . . .		1·43	11·51	1381	11125	14296	78	107718
13	Locomotive Webb .		9·83	10·28	9495	9930	14004	70	664650
14	,, Marié .		4·62	10·65	4462	10287	14600	70	312340
15	,,	Coke.	12·57	8·22	12142	7940	13550	58	704236
16	,,	Coke.	13·73	8·94	13263	8636	13550	63	835569
17	,,	Coke.	6·76	10·01	6530	9669	13550	71	463630
18	,,	Coke.	7·39	11·2	7138	10819	13550	77	549626
19	Torpedo-boat . .		12·54	8·37	12113	8085	14727	54	654102
20	,, . .		14·86	7·78	14354	7523	14727	51	732054
21	,, . .		17·90	7·49	17291	7235	14727	49	847259
22	,, . .		20·74	7·04	20034	6800	14727	46	921564

fuel to the water in the boiler, and the actual thermal units in the fuel; whence the efficiency of the boiler in respect to its fuel was worked out. In the last column was given what might be called a

figure of merit, which was obtained by simply multiplying the efficiency F of the boiler by the number of thermal units C that it transmitted. In this way the conclusion was arrived at that in these locomotive boilers, taking into account both speed of evaporation and economy of evaporation, the results were something like six or eight to one in favour of the locomotive as compared with the portable-engine or Lancashire boilers. In Mr. Webb's compound locomotive, the boiler evaporated, from and at 212°, 9·83 lbs. of water per square foot of heating surface per hour; and at that good and economical rate of evaporation it was evaporating 10·28 lbs. per lb. of fuel, also from and at 212°. It would be difficult even with a very good Cornish boiler to do anything like the same. The nearest example in the Table was a portable-engine boiler, which it would be seen was evaporating 9·93 lbs. of water per lb. of fuel, but at the rate of only 3·56 lbs. per square foot of heating surface per hour; so that with the same economy one of these two boilers was evaporating nearly three times as fast as the other. This marked combination both of rapidity and economy of evaporation in the case of the locomotive boilers he attributed to the fact that the tremor of the whole machine produced such a molecular disintegration of the fire as to provide for exceedingly complete combustion of the fuel on the grate; and that the same tremor also caused each nascent bubble of steam to become dislodged from the heating surface as soon as it was formed, thus preventing any clinging of the bubbles, and producing an efficient circulation.

Mr. Robinson asked whether the Lancashire boilers included in the Table were those with two internal flues, and whether there were any tubular connections in the flues.

Mr. Halpin said the Lancashire boilers had double flues with cross Galloway tubes; and the result in these boilers—multiplying the efficiency F taken as a whole number and not as a decimal, into the rapidity C in units of heat transferred per hour per square foot of heating surface — came out one to eight as compared with

locomotive boilers. A simpler "figure of merit," by which to judge the combined economy and rapidity of evaporation of a boiler, he considered might be obtained by multiplying the evaporation A in lbs. per square foot of heating surface per hour, from and at 212°, by the evaporation B per lb. of fuel, also from and at 212°: thus if, as in example No. 13 in the foregoing Table, the rapidity of evaporation were 9·83 and the quantity evaporated 10·28, the figure of merit would be $9 \cdot 83 \times 10 \cdot 28 = 101$.

There was one other point on which he could not agree with the author. On page 91 it was said "These satisfactory results confirm what the author's father always maintained, namely that locomotives ought to have large heating surface and large cylinders; he always built his own locomotives by that rule." For locomotive superintendents this was a very good rule; because the larger the engine, the more easily was it worked and maintained. But there were people who held that locomotives were intended for other objects than merely to burn little fuel and to keep out of the repairing shops as long as possible, and that they were naturally required to earn good dividends; and he could hardly conceive that the engine used in the author's experiments was a favourable example of a high-class engine in this last respect, for it was exceedingly heavy and did very little work. The only comparative example he could at present conveniently refer to was the compound locomotive described last year by Mr. Webb. It might be objected that it would not be fair to compare a high-speed express engine with an engine running so slowly as that used by the author, which was practically a goods engine running with light trains; but he could not get any better example at the time. In the *Revue générale des Chemins de fer* for July 1881 M. Marié had given a valuable series of calculations, but had left out the weight of the engine, which was an express engine; it was therefore impossible to compare his results with what was being done in this country.

With regard to the question of weight, the separate weights of the engine and tender were not given in the paper; but it might be assumed no doubt pretty nearly that the engine weighed 43·83 tons; and it developed 383 HP. Mr. Webb's engine weighed 34·75 tons

and indicated 495 HP. Thus M. Marié's engine developed 8·67 HP. per ton of weight, while Mr. Webb's indicated 14·21 HP. per ton. The only objection there could be to this comparison was simply that a low-speed engine was compared with a high-speed. He did not know what the actual prices of the two locomotives were; but assuming engines alone, without tenders, to cost £80 per ton, this would give £3506 for M. Marié's engine, and £2780 for Mr. Webb's, showing a difference of £726 against the heavy engine; and taking this at 15 per cent. per annum, for interest on outlay of capital and for depreciation, there would be a balance of £110 against the heavy engine before any profit could be taken into account. One fact which he gathered from the paper in the *Revue des Chemins de fer* was that the author's engines burnt on an average about £320 worth of fuel per annum: so that of course where fuel was dear, and each engine was burning a large value per annum, there might be a cause for increasing the weight of the engine in order to economise fuel; but he did not think the saving in fuel would be sufficient to justify the extra outlay that had to be incurred for the greater weight of engine; besides which Mr. Webb's engine gave almost as economical results, while evaporating with double the rapidity.

From page 99 of the paper it seemed that the author did not think the compound engine could give better results than those given by the engine which he had described. But with this opinion he himself could not at all agree; because figures which had lately been published* respecting the performances of the compound engine running on a trip from London to Carlisle with a passenger train showed roughly the following results. The run was say 300 miles, and the speed between stations averaged over 44 miles per hour; and assuming the ordinary formula for traction, as measured in the engine cylinder,—namely, traction in lbs. per ton $= 8 + \frac{(\text{speed in miles per hour})^2}{171}$,—under those circumstances the traction would be 19·5 lbs. per ton weight; which, with the total load of 214·5 tons and the net running consumption of

* See 'Engineering,' 1 Feb. 1884, p. 106.

28·26 lbs. per mile, would give a consumption of 2·51 lbs. of coal per indicated HP. per hour; but whether that 19·5 lbs. per ton was right or not, as the figure for traction, he could not say. On the other hand the results got at by M. Regray's elaborate series of experiments on the Eastern Railway of France would give for engines and carriages of that class and at that speed 27 lbs. traction per ton weight, which made a great difference, and would bring the consumption down to only 1·81 lbs. of coal per indicated HP. per hour; but he hardly thought the amount could be so low. The traction he thought was too high as deduced from the French experiments; and the question of traction was one that ought if possible to be more accurately determined.

With regard to what was said in page 96 of the paper as to the use of exhaust-steam injectors on locomotives, he believed there was a very wide field open for the application of these injectors to locomotives, not alone on account of economy of fuel, but also because in the locomotive the water itself was a great consideration; for he thought it was now proved beyond dispute that by the use of these injectors an average of 15 per cent. saving in water could be effected, while it was clear that a saving of at least 10 per cent. of the waste heat could be effected. Hence he considered the exhaust-steam injectors were one of the means that might in future be employed for still further improving the locomotive.

With regard to Mr. Tomlinson's remarks about the compound locomotives being nursed, he had had the pleasure of going on one of them from London to Crewe with a fairly heavy express train in not very good weather, and on the whole run of 150 miles he certainly did not see the slightest attempt at nursing in any way which he could detect. He never rode on an engine that went more smoothly or satisfactorily; and he certainly never rode before on an engine that kept the steam just simmering half a pound or so over the safety-valves. The valves were set to 150 lbs., and the steam just kept on blowing slightly during the whole time. There were now twenty of these compound engines on the London and North Western Railway.

Mr. Michael Longridge said the remarks made by Mr. Ramsbottom entirely upheld the view he had taken for some time,—namely that the economy resulting from compound engines had been due not so much to the compound system as to the increase of pressure and the increased grade of expansion; and he would quote some figures illustrating that point from a rather curious case which had come within his own experience. In most compound engines, in order to get the power needed, the cylinder surface had to be increased very materially over the surface required in a single engine to develope the same power. In the case he referred to there was an engine with a 38-inch cylinder, 5 ft. stroke, 330 HP., and 47 lbs. steam, cut off at one-fifth of the stroke. In compounding the engine the low-pressure cylinder was not increased, but a new high-pressure cylinder of 24 ins. diameter was put behind it, so that the condensing surface was the minimum that could be got in a compound engine. To get the required power, the boiler pressure had to be raised 10 lbs.; notwithstanding which the coal consumption for a year before and a year after the change remained exactly the same, and the ratio of expansion remained exactly the same. The only difference was that in the single engine the quantity of water present at the commencement of the stroke—that is, at the end of the admission—was 34 per cent., and at the end of the stroke 14 per cent.; while in the compound engine the quantity of water present in the small cylinder at the end of the admission was 13·2 per cent., and at the end of the expansion in the large one 33 per cent., simply reversing the condensation from one end of the expansion to the other. To his mind that was a very conclusive proof that there was no particular economy in compounding *per se;* and hence, that the economy resulting from compound engines had been due to the increase of pressure. He believed further that the limit had now been very nearly if not quite attained at which economy was possible from increase of pressure. The losses resulting from increased friction and wear and tear ate up very fast the small gain obtained by increasing the pressure from say 80 up to 100 lbs. per square inch in condensing engines. In non-condensing the limit would naturally be higher.

Mr. W. E. Rich said there were one or two points in the paper which were interesting to those who were not locomotive engineers. The minimum coal consumption noted on page 91 appeared to have been 2·48 lbs. per indicated HP.; and taking the steam produced as 8·08 lbs. per lb. of coal, he gleaned that the steam consumption was 20 lbs. weight per HP. per hour. Comparing these results with those obtained at Cardiff in 1872 from portable engines having certainly a lower steam pressure, he found that the lowest coal consumption at Cardiff was 2·38 lbs. per indicated HP., while in the locomotive it was 2·48 lbs., or within 5 per cent. of the same result, the locomotive being rather worse than the portable engines. The steam consumption in this locomotive was 4 lbs. better per HP.: the portable engine used 24 lbs. weight of steam per HP. per hour, while the locomotive used 20 lbs. Here again it had to be remembered that the steam pressure in the locomotive was something over 100 lbs., up to even 130 or 140 lbs.; while in the portable engine it was only 80 lbs. One further point regarding this comparison was that at Cardiff it had been impossible to get anything approaching these high results without the use of steam-jackets. The paper did not say whether these locomotives in any case were furnished with steam-jackets; but no engine without them at Cardiff got results within 50 per cent. of those he had mentioned.

Mr. J. A. F. Aspinall said with regard to compound engines he had only heard what Mr. Webb had to say about them; and he had often been told by him that he was very well satisfied with the result; that he had tried ten of them running continuously for a considerable period, and that they were burning something like 6 lbs. of coal less per mile than engines with similar wheels and with 17 by 24 inch cylinders, which had been working the passenger trains previously. He was sorry Mr. Webb was not there to tell them exactly what he had done; but from what he had been told by him he certainly did not think the compound locomotives were a failure. He did not know whether Mr. Webb had yet made goods engines compound, but he was going to do so; and it would be very interesting to see whether that experiment was successful.

Mr. D. BANDERALI quite agreed in the importance of Mr. Webb's compound engines, and was following with the greatest interest all that was being done in that direction. He knew that what at first was an experiment seemed now to have a very good future before it; and he should be glad if Mr. Webb could give any further information as to the results of the experiments he was just now making.

Mr. ROBINSON said there would very soon be an opportunity in France of judging of Mr. Webb's system. M. Meyer, of the Western Railway, was having a compound locomotive made, and engineers in that country would then have an opportunity of seeing what that could do.

Mr. ARTHUR PAGET said he would venture before the discussion closed to point out that—as they all so much regretted the absence of Mr. Webb, and as Mr. Tomlinson and several others had in the most polite manner expressed a doubt as to the results which Mr. Webb was supposed to have obtained, and as even Mr. Robinson had referred to the economy which Mr. Webb "had an impression on his own mind" had been obtained, "and had succeeded in conveying it to the minds of others"—which was a rather doubtful form of expression—it would be at least only fair to Mr. Webb, as he was unfortunately unable to be present, and still more valuable to the Institution, that he should be asked if he would be kind enough to add an appendix to the paper and discussion, replying to the remarks that had been made on the subject of the saving of coal proved to exist in the use of his compound engines.

Mr. TOMLINSON said when he made use of the word "nursing" he did not mean jockeying. He simply meant that Mr. Webb had made a new engine, and that he with all his men would naturally take the greatest possible interest in making it do its best for the time as a new idea, only ten of these engines being in use at the time when Mr. Webb read his paper last summer. If he himself were to bring out anything new in his own shops, and took his foreman into his confidence, he should expect that the latter would take as much

interest in it for the time as himself; and therefore it would necessarily get nursed, in his sense of the term, until it became common.

Mr. McDonnell thought it should be understood that, without any intentional nursing, a locomotive superintendent, if he were going to try an experiment with an engine, did not pick out the worst driver but chose a good one. But then, without any intention whatever of producing an exceptional result, an average result was not produced under these circumstances. It was well known that the difference between a good driver and a bad one in the consumption of coal was very great. But in an experiment such as Mr. Webb was making, it should be understood that he very properly had not given his engine into the hands of even an average driver, but he had taken a good driver,—a man who would be careful of it, not nursing it in the improper sense of the word, but in the proper sense.

Mr. Tomlinson said, in corroboration of Mr. McDonnell's remarks, he had on the Metropolitan Railway three or four drivers invariably at the top of the list in each section of the line, and three or four invariably at the bottom of the list. He allowed them 33 to 34 lbs. of coal per mile, and gave a monthly premium on all saving below 34 lbs. The three or four at the top generally got a premium of from 11*s.* to 12*s.* a month, by saving about 4 lbs. per mile, if instead of burning 34 lbs. they burned 30 lbs. per mile. The men at the bottom of the list were invariably up to 37 and 38 lbs. per mile, or nearly 25 per cent. in excess of the best drivers. On the St. John's Wood line, with an allowance of 29 lbs. per mile, he had men who invariably showed the smallest consumption, month after month getting from 10*s.* to 11*s.* premium by burning only from 29 down to 26 lbs. per mile while others burned from 29 up to 33. The latter were very good men, and worth their weight in gold in so far as that they never gave any trouble or got their employers into any difficulty; but they could not be economical, because they did not understand how to be so.

Mr. C. E. Cowper called attention to two points in the paper. One was as to the duration of the trial. When the consumption of coal in the author's trials was spoken of in comparison with the consumption of coal in stationary engines and boilers, the duration of the trial was of great importance; for in the case of a pumping or other stationary engine no one would think of relying upon a trial of only one hour's duration. By careful stoking and slow working it was possible to show almost no consumption at all in a trial lasting only one hour. It might be impossible under the circumstances of the author's trials to make them of longer duration; but at the same time their shortness should be considered in comparing them with trials of stationary engines. The other point was, that the letters I.H.P. in the paper did not there represent that which they were usually taken to represent. They did not there denote the actual indicated horse-power, but something which the author calculated would be or ought to be the indicated horse-power under the circumstances that obtained at the trial; the figures must therefore be taken for what they were worth.

The President was sorry to say the author of the paper was not able to be present on account of illness. At one part of the discussion it had seemed to himself that, if any one had proposed a vote of censure upon an engine-driver who could be said to have nursed his boiler, it would probably have been carried; but now the view seemed to be rather the opposite, and that the driver who did not nurse his engine was the man who laid himself open to censure. For in reality if the driver was not nursing his engine, he was doing something short of that which he ought to be doing. His own experience had always been that, when he himself had been watching an experiment, he got very much better results, either in firing boilers or in other work, than was got under the regular current work of the day; and he believed this observation applied with great force to firing an engine, because it was really one of the most delicate operations with which a working man could be entrusted. They were standing, as it were, between two difficulties; either the fireman neglected to admit a proper quantity of air into the fireplace,

in which case of course by a well known law the coal was imperfectly consumed; or else, on the other hand, too much air was admitted, whereby of course a very much larger quantity of gaseous matter was carried off, taking with it a vast amount of heat, far more he apprehended than most engineers had any idea of. If the quantity of gaseous matter were considered which was passing through a locomotive engine boiler, carrying along with it the quantity of heat represented as he believed by a temperature of something like 800 or 1000 degrees, it would be found that there might arise an enormous loss from that cause alone. So that the mid course had to be steered between these two extremes,—the extreme of not admitting air enough, and the extreme of admitting too much air. Though not feeling competent, in the presence of so many locomotive engineers, to speak with any authority in regard to the mechanical part of a locomotive engine, he might say that the author of the paper really seemed to have covered the ground very completely on the present occasion. He did not say that the conclusions were necessarily correct; but the author seemed to have covered the ground more completely than was generally the case in papers of that description, because in addition to the purely mechanical portion of his subject he also went very carefully into the chemical part, which was a very important one in matters of that kind. Under these circumstances he had very much pleasure, and he was sure the Members would be very glad to agree with him, in awarding a hearty vote of thanks to the author of the paper.

Mr. F. W. Webb, in response to the appeal made to him in the discussion, has written to say that, having unfortunately been unable to be present at the reading and discussion of M. Marié's paper, he does not purpose answering the objections raised to his method of compounding, as he would prefer to let the continued working of the engines show what they are capable of doing. Their performance continues to give very satisfactory results. Twenty of these compound engines are now doing the heaviest express main-line work on the London and North Western Railway under

some twenty different drivers; and the average result—which is the only fair one to give, without going into all the details of loads, gradients, speeds, &c.—is that up to 30 April 1884 they have run altogether 582,716 miles on a consumption of 142,785 cwts. of coal, or an average of 27·4 lbs. per mile. The first engine, "Experiment," which was turned out in February 1882, is answerable for 134,323 miles; and the next four, which were turned out in March and April 1883, have averaged 54,946 miles each; so that it will be seen the results are very regular, and the performance for a whole year is over 1000 miles per week. In some more engines now building for the same work it has not been found necessary to make any alterations in the proportions; but plans are being got out for engines capable of dealing with trains of 300 tons gross weight at express speeds.

On 27 May 1884 a trial was made of a compounded side-tank engine, No. 2063, converted from one of the type used on the Metropolitan Railway. This engine, weighing 46·850 tons empty, took a train of twenty-five large six-wheel coaches, weighing 256·825 tons empty, or a gross load of 303·675 tons empty, up the Madeley incline from Crewe to Whitmore, a distance of 10·59 miles in 21 minutes with a rise of 201 feet, giving an average speed of 30 miles per hour up an average gradient of 1 in 278. This experiment was not tried to see the amount of fuel consumed, but to see what weight of train the engine would deal with on this incline, the cylinders being high-pressure 13 ins. and low-pressure 26 ins. diameter with 24 ins. stroke, wheels 5 ft. 9 ins. diameter, and boiler pressure 150 lbs. per sq. inch. The same engine has been working local stopping trains for eleven days between Liverpool and Crewe, viâ Northwich, with an average gross load of 131 tons stock, including the engine; the total miles run have been 1730, and the fuel consumed 330 cwts., giving an average consumption of 21·3 lbs. per mile.

In the trip with the Scotch express from London to Carlisle on 26 October 1883, to which reference has been made in the discussion, the engine and tender No. 300 when starting from Euston weighed 62·650 tons; the train of twelve vehicles weighed

141·337 tons empty, and at Crewe a thirteenth coach was added, weighing 10·475 tons empty, bringing the train up to 151·812 tons, exclusive of passengers and luggage. The coal consumed was 79 cwts. in the run of 300 miles, or 29·46 lbs. per mile; and deducting 1·20 lb. per mile for lighting up, the actual consumption in running was 28·26 lbs. per mile. The water used was 7546 gallons; and the evaporation was therefore $\frac{7546 \times 10}{79 \times 112} = 8 \cdot 5$ lbs. of water per lb. of coal.

M. MARIÉ, regretting that ill-health deprived him of the pleasure of attending the meeting, has since sent the following reply to the observations made in the discussion:—

In reference to the remark by Mr. Robinson, that "the author seemed to hesitate as to whether that economy could be produced by a change of mechanism or by an increased pressure," the author considers that any great economy of fuel can only be obtained by employing at the same time both increased pressure and improved mechanism, and that the greatest improvement in mechanism is that obtained in Mr. Webb's compound engines. The boilers of those engines are remarkably light, because they are made of the best quality of steel, which allows of the plates being thin, in spite of the high pressure of steam.

In the trial made by Mr. Tomlinson many years ago of a high boiler-pressure, the author is not surprised that the results were not good, because ordinary locomotives are not suitable for the great expansion attendant upon the use of high pressure. There will doubtless at first be difficulties in using higher pressures, but the author anticipates that those difficulties will be overcome in the course of a few years.

As to the use of indicators for locomotive engines, it is true that during the last few years indicators have been much improved, especially by M. Marcel Deprez and M. Regray. The indications obtained from these instruments are free from errors due to the oscillation of the spring. The author believes the American indicator referred to by Mr. Halpin is made on the same principles,

and that it also will give accurate results on locomotives. Generally he thinks that most of the experiments formerly made with indicators on locomotives have been inaccurate, but that accurate indicator diagrams can now be obtained from locomotive engines. As regards the friction of the pistons and valve-gear of locomotives, there is naturally a difference between M. Regray's results and the author's, because the engines were quite different, and also because in the experiments on the Eastern Railway of France the engine was exerting only a small portion of its power.

In connection with Mr. Halpin's interesting comparison between boilers of different kinds, it must be noticed that the water consumed by a boiler is not the true measure of the evaporation, but is subject to a correction for priming, which varies in actual practice between 4 and 12 per cent. deduction.

The experiments given in the author's paper, as Mr. Halpin rightly points out, cannot be compared with those on Mr. Webb's engine, on account of the great difference between the working of the engines in the experiments; and the object of the paper has been to compare an ordinary locomotive with the best stationary engines, and with the results deduced from the theory of thermodynamics. Experiments similar to those given in the paper cannot be made with the compound locomotive until a compound goods engine has been built. But meanwhile experiments might be made on the express compound engine with the American indicator already referred to; and then a comparison could be made with the author's experiments by determining the exact consumption of fuel per indicated horse-power per hour in the compound locomotive: that would be an experiment of great importance, giving the exact value of the compound system.

In the meantime the author may add the following results of a month's accurate trial, made, not with a slow train, but with one of the express locomotives of the Paris and Lyons Railway, referred to in page 100 of the paper. It is the result obtained from the working of the engine with express trains from Lyons to Valence and back during the month of September 1883, about the time at which Mr. Webb's experiment, referred to by Mr. Halpin, was made. Between

Lyons and Valence the curves are easy and the gradients light, the line being almost level; the trains are the same weight each way, and the speed also the same.

Total distance run during the month		3,480 miles.
Average speed		$43\frac{1}{2}$ miles per hour.
Weight of engine loaded		49 tons.
„ tender „	35 tons	
„ train „	167 tons	
„ train with tender and without engine . .		202 tons.
Total consumption of fuel during the month, including lighting up, standing at stations, &c. . . .		95,022 lbs.
Consumption of fuel per mile, including lighting up, &c.		27·30 lbs.
Consumption of water per lb. of fuel		8·90 lbs.

The consumption of fuel per ton-mile of train (including tender) is therefore $\frac{27 \cdot 30}{202} = 0 \cdot 135$ lb. per ton-mile. This is less than in Mr. Webb's experiment of October 1883, where however the weight given of the train is that of the carriages empty, while the weight of the author's train includes that of passengers and luggage, which was accurately ascertained. Also the line between Lyons and Valence is almost level, while between London and Carlisle the average gradient is 1 in 110 or 0·9 per cent. for one-thirteenth of the total distance, which corresponds with a general average gradient of 1 in 1440 from London to Carlisle. Although so low an average gradient is but a small matter, it is clear the consumption would have been somewhat less on a level line. No doubt Mr. Webb could give the exact consumption per ton-mile of train (including tender) on a level, which the author believes would be found to be almost the same as in the Paris and Lyons express engine; probably a little lower, owing to the higher boiler-pressure in the compound engine.

In any comparison of Mr. Webb's engines with others, the weight of the tender should be included in that of the train, because the locomotives on the London and North Western Railway pick up water while running, which allows their tenders to be much lighter

than the author's. It is also important that the statement of fuel consumption should give the total consumption, including lighting up and everything else. However carefully comparisons of this kind may be made, they are yet open to the objection that the traction per ton of train is perhaps not the same for English and for French carriages.

The consumption of only 27·30 lbs. of coal per mile will no doubt be considered very low for such heavy express trains; and the Paris and Lyons express engines are certainly very economical, as stated in the paper, owing both to their large cylinders, which allow good expansion, and also to their large heating surface, which gives a high evaporation per lb. of coal. Such a good result the author considers could not be obtained from any ordinary locomotive not possessing these advantages. Moreover the engine-driver was the best on that section of the line. The trial having been made in September 1883, the consumption of fuel would be a little higher in winter, especially when very cold.

Though further increase of steam-pressure above the present limits is not considered by Mr. Longridge likely to prove economical, the author has shown in page 99 of the paper how the theory of thermodynamics encourages the hope that it will be advantageous. The want of success attending trials that have been made of higher pressures in ordinary locomotives has been owing to their not admitting of sufficient expansion; and the author anticipates that the compound locomotive will prove admirably suitable for higher pressures, in consequence of its expanding the steam further.

In reply to Mr. Rich's enquiry, none of the Paris and Lyons engines are furnished with steam-jackets, which the author looks upon as an unnecessary complication for locomotives, in consequence of their high piston-speed.

Though the author's trials did not occupy more than an hour each, it will be seen from pp. 85–7 of the paper that no error can arise from that cause, inasmuch as the measurement of the fuel consumption gives the whole of the fuel fed into the firebox, including lighting up and everything: which is not generally the case in trials of stationary engines.

Already the results from the compound locomotive with its higher pressure may be perhaps a little better than from the author's engines, in which the boiler-pressure does not exceed 128 lbs. per sq. inch; and he is sure that Mr. Webb's boilers will be made to carry still higher pressures in the course of a few years. Ordinary locomotives hardly admit of expanding advantageously from a higher boiler-pressure than 128 lbs. per sq. inch; whereas the compound locomotives with higher pressures will in the author's opinion show a decided superiority not only in economy of fuel but also in power, which is a very important point in railway working.

ON PORTABLE RAILWAYS.

By M. PAUL DECAUVILLE, of Petit-Bourg (Seine and Oise), France.

Narrow-gauge railways have been known for a very long time in Great Britain. The most familiar lines of this description are in Wales, and it is enough to instance the Festiniog Railway (2 feet gauge), which has been used for the carriage of passengers and goods for nearly half a century. The prosperous condition of this railway, which has been so successfully improved by Mr. James Spooner and his son Mr. Charles Spooner, affords sufficient proof that narrow-gauge railways are not only of great utility but may be also very remunerative.

In Wales the first narrow-gauge railway dates from 1832. It was constructed merely for the carriage of slates from Festiniog to Port-Madoc; and some years later another was made from the slate quarries at Penrhyn to the port of Bangor. As the tract of country traversed by the railways became richer by degrees, the idea was conceived of substituting locomotives for horses, and of adapting the line to the carriage of goods of all sorts, and finally of passengers also.

But these railways, although very economical, are at the same time very complicated in construction. Their arrangements are based upon the same principles as railways of the ordinary gauge, and are not by any means capable of being adapted to agriculture, to public works, or to any other purpose where the tracks are constantly liable to removal. These permanent narrow-gauge lines, the laying of which demands the service of engineers, and the maintenance of which entails considerable expense, suggested to the author, then a gentleman-farmer and distiller at Petit-Bourg, near Paris, the idea of forming a system of Portable Railways composed entirely of metal, and capable of being readily laid. Cultivating one of the largest

farms in the neighbourhood of Paris, he contemplated at first nothing further than a farm railroad; and he contrived an extremely portable plant, adapted for clearing the land of beetroot, for spreading manure, and for the other needs of his farm.

From the beginning, in his first railroads, the use of timber materials was rigidly rejected; and all parts, whether the straight or curved rails, crossings, turntables, &c., were formed of a single piece, and did not require any special workman to lay them down. By degrees he developed his system, and erected special workshops for the construction of his portable plant; making use of his farm, and of some quarries of which he is possessed in the neighbourhood, as experimental places. At the present time this system of portable railways is in use for all the purposes of agriculture, of commerce, of manufactures, and even of war.

Within so limited a space it would be impossible to give a detailed description of the rails and fastenings used in all these different applications. The object of this paper is rather to direct the attention of mechanical engineers to the various uses to which narrow-gauge portable railways may be put, to the important saving of labour which is effected by their adoption, and to the ease with which they are worked.

The success of the Decauville railway has been so rapid and so great that many inventors have entered the same field; but they have almost all constructed the portable track with sleepers that can be detached. There are thus, at present, two systems of portable tracks; those in which the sleepers are capable of being detached, and those in which they are not.

The portable track of the Decauville system is not capable of so coming apart. The steel rails and sleepers are riveted together and form only one piece. The chief advantage of these railways is their great firmness; besides this, since the line has only to be laid on the surface just as it stands, there are not those costs of maintenance which become unavoidable where the sleepers are fixed by means of bolts, clamps, or other adjuncts, only too liable to be lost. Moreover, tracks which are not capable of separation are lighter and therefore more portable than those in which the sleepers can be detached.

With regard to sleepers, a distinction must be drawn between those which project beyond the rails, and those which do not so project. The author has adopted the latter system, because it offers sufficient strength, while the lines are lighter and less cumbersome.

Where at first he used flat iron sleepers, he now fits his lines with dished steel sleepers, in accordance with Figs. 1 and 2, Plate 4. This sleeper presents very great stiffness, at the same time preserving its lightness; and the feature which specially distinguishes this railway from others of the same class is not only its extreme strength but above all its solidity, which results from its bearing equally upon the ground by means of the rail-base and the sleepers.

In special cases, the author provides also railroads with projecting sleepers, either of flat steel beaten out and rounded, or of channel iron; but the sleeper and the rail are always inseparable, so as to avoid lessening the strength, and also to facilitate the laying of the line. If the ground is too soft, the railway is supported by bowl sleepers of dished steel, Figs. 3 and 4, Plate 4, especially at the curves; but the necessity for using these is but seldom experienced. The sleepers are riveted cold. The rivets are of soft steel, and the pressure with which this riveting is effected is so heavy that the sleepers cannot be separated from the rails, even after cutting off both heads of the rivets, except by heavy blows of the hammer, the rivets being driven so thoroughly into the holes in the rails and sleepers as to fill them up completely.

The jointing of the rails is exceedingly simple. The rail to the right hand, Fig. 5, Plate 4, is furnished with two fish-plates: that to the left has a small steel plate riveted underneath the rail and projecting $1\frac{1}{4}$ inch beyond it. It is only necessary to lay the lengths end to end, making the rail which is furnished with the small plate come in between the two fish-plates, and the junction can at once be effected by fish-bolts. A single fish-bolt, passing through the holes in the fish-plates, and through an oval hole in the rail-end, is sufficient for the purpose.

With this description of railway it does not matter whether the curves are to the right or to the left. The pair of rails are curved to

a suitable radius, Fig. 6, Plate 5, and only need turning end for end to form a curve in either direction. The rails, Fig. 14, Plate 7, weigh 9 lbs. per yard, 14 lbs., 19 lbs., and 24 lbs. per yard; and are very similar to the rails used on the main railways of France, except that their base has a greater width in proportion. As to the strength of the rail, it is much greater in proportion to the load than would at first sight be thought: all narrow-gauge railways being formed on the principle of distributing the load over a large number of axles, and so reducing the amount on each wheel. For instance, the 9 lbs. rail used for the portable railway bears easily a weight of half a ton for each pair of wheels.

The distance apart between the rails differs according to the purpose for which they are intended. The most usual gauges are 16, 20, and 24 inches. The line of 16 ins. gauge, with 9 lbs. rails, although extremely light, is used very successfully in farming, and in the interior of workshops.

A length of 16 ft. 5 ins. of 16 ins. gauge, with 9 lbs. steel rails and sleepers &c., weighs scarcely more than 1 cwt., and may therefore be readily carried by a man placing himself in the middle and taking a rail in each hand.

The members of the Institution who recently visited the new Port of Antwerp will recollect seeing there the portable railway which Messrs. Couvreux and Hersent had in use; and as the works at the Port of Antwerp gave rise to the idea of this paper, it will be well to begin with a description of this style of contractors' plant.

The earth in such works may be shifted by hand, horse-power, or locomotive. For small works the railway of 16 ins. gauge, with the 9 lbs. rails, is commonly used, and the trucks carry double-equilibrium tipping-boxes, containing 9 to 11 cub. ft. These wagons, of smaller size than those shown in Figs. 17 and 18, Plate 9, but of similar construction, having tipping-boxes without any mechanical appliances, are very serviceable; the box, having neither door nor hinge, is not liable to need repairs, and it keeps perfectly in equilibrium upon the worst roads. To tip it up to the right or

left, as shown dotted in Fig. 17, it must simply be pushed from the opposite side, and the contents are at once emptied clean out. In order that the bodies of the wagons may not touch at the top, when several are coupled together, each end of the wagon is furnished with a buffer, composed of a flat iron bar cranked, and provided with a hanging hook.

Plant of this description is now being used in an important English undertaking at the port of Newhaven, where it is employed not only on the earthworks, but also for transporting the concrete manufactured with Mr. Carey's special concrete machine.

These little wagons, of from 9 to 11 cub. ft. capacity, run along with the greatest ease; and a lad could propel one of them with its load for 300 yards at a cost of 3*d.* per cubic yard. In earthworks the saving over the wheelbarrow is 80 per cent.; for the cost of wagons propelled by hand comes to 1*d.* per cubic yard carried 100 yards, while to go this distance with a barrow costs 5*d.* A horse draws without difficulty, walking by the side of the line, a train of from 8 to 10 trucks on the level, or 5 on an incline of 7 per cent. (1 in 14).

One mile of this railway, of 16 ins. gauge and 9 lbs. steel rails, with 16 wagons, each having double-equilibrium tipping-box containing 11 cubic feet, and all accessories, represents a weight of 20 tons,—a very light weight, if it is considered that all the materials are entirely of metal. Its net cost price per mile is £450, the wagons included.

Large contracts for earthwork with horse haulage are carried on to the greatest advantage with the railway of 20 ins. gauge and 14 lbs. rails. The length of 16 ft. 5 ins. of this railway weighs 170 lbs.; and so can be carried easily by two men, one at each end. The wagons most in use for these works are those with double-equilibrium tipping-boxes, holding 18 cub. ft., Figs. 17 and 18, Plate 9. These are now being employed in one of the greatest undertakings of the present time—namely, the cutting of the Panama Canal, where there are in use upwards of 2700 such wagons and more than 35 miles of track.

A mile of this railway of 20 ins. gauge with 14 lbs. rails,

together with 16 wagons of 18 cubic feet capacity, with appurtenances, costs about £660, and represents a total weight of 33 tons.

This description of plant is used for all contracts exceeding 20,000 cubic yards.

A very curious and interesting use of the narrow-gauge line, and the wagons with double-equilibrium tipping-box, was made by the Société des Chemins de fer Sous-Marins on the proposed tunnel between France and England. Fig. 19, Plate 10, represents a section of the tunnel, with two lines of rails, on one of which is a train of wagons, and on the other an inspection carriage with two seats. The line used is that of 16 ins. gauge, with 9 lbs. rails.

The first heading of the tunnel, which was driven by means of a special machine by Colonel Beaumont, had a diameter of only 2·13 m. (7 ft.); the tipping-boxes have therefore a breadth of only 2 feet, and contain $7\frac{1}{4}$ cubic feet. The boxes are perfectly balanced, and are most easily emptied. The wagons run on two lines, the one being for the loaded trains, and the other for the empty trains.

The engineers and inspectors, in the discharge of their duties, make use of the Lilliputian carriages shown in Figs. 19 and 20, Plate 10. The feet of the travellers go between the wheels, and are nearly on a level with the rails: nevertheless they are tolerably comfortable. They are certainly the smallest carriages for passengers that have ever been built; and the builder prophesies that these will be the first to enter England through the Channel Tunnel.

One of the most important uses to which a narrow-gauge line can be put is that of a military railway. The Dutch, Russian, and French governments have tried it for the transport of provisions, of war material, and of the wounded, in their recent campaigns. In Sumatra, in Turkestan, and in Tunis, these military railroads have excited much interest, and have so fully established their value that a short description will here suffice.

The campaign of the Russians against the Turcomans presented two great difficulties, in the crossing of districts where water was extremely scarce or failed entirely, and in the victualling of the

expeditionary forces. The latter object was completely effected by means of 67 miles of railway, of 20 ins. gauge and 14 lbs. steel rails, with 500 carriages for food, water, and passengers. The rails being laid simply on the sand, small locomotives could not be used, and had to be replaced by Kirghiz horses, which drew with ease from 16 cwts. to 1 ton for 25 miles per day.

In the Tunisian war this railroad of 20 ins. gauge with 14 lbs. rails was replaced by that of 2 feet gauge, with 14 lbs. and 19 lbs. rails. There were quite as great difficulties as in the Turcoman campaign, and the country to be crossed was entirely unknown. The observations made before the war spoke of a flat and sandy country. In reality a more uneven country could not be imagined: alternating slopes of about 1 in 10 continually succeeded each other, and before reaching Kairouan 7½ miles of swamp had to be crossed. Nevertheless the horses harnessed to the railway carriages did on an average twelve to seventeen times the work of those working ordinary carriages. In this campaign also, on account of the steep ascents, the use of locomotives had to be given up. The track served for the conveyance not only of victuals, war material, and cannon, but also of the wounded; and a large number of the survivors owe their lives to this railway, which supplied the means of their speedy removal, and without great sufferings, from the temporary hospitals, and of carrying them to places where more care could be bestowed upon them.

The carriages which did duty in this campaign are shown in Plates 11 and 12. They are wagons with a platform entirely of metal, resting upon eight wheels. The platform is 13 ft. 1 in. long and 3 ft. 11 ins. wide. The total length over buffers is 14 ft. 9 ins., as shown. This carriage may be turned at will into a goods wagon; or into a passenger carriage for sixteen persons, with seats back to back, as in Figs. 21 and 22, Plate 11; or into an ambulance wagon for eight wounded persons, as in Figs. 23 and 24, Plate 12.

For the transport of cannon the French military engineers have adopted small trucks similar to Figs. 15 and 16, Plates 7 and 8. A complete equipage, capable of carrying guns weighing from 3 to 9 tons, is composed of trucks with two or three axles, each being

fitted with a pivot support, by means of which it is rendered possible to turn the trucks, carrying the heaviest pieces of ordnance, on turntables, and to push them forwards without their going off the rails at the curves.

The trucks which have been adopted for the service of the new forts in Paris are drawn by six men, three at each end of the gun; and these are capable of moving with the greatest ease guns weighing 3 tons.

The narrow-gauge railway was tested during the war in Tunis more thoroughly than in any preceding campaign; and the military authorities decided, after peace had been restored in that country, to maintain the narrow-gauge railways permanently; this is a satisfactory proof of their having rendered good service. The line from Sousse to Kairouan is still open for regular traffic. In January, 1883, an express was established, which leaves Sousse every morning and arrives at Kairouan—a distance of forty miles—in five hours, by means of regularly organised relays. The number of carriages and trucks, for the transport of passengers and goods, is 118.

The success thus attained by the narrow-gauge line goes far to prove how unfounded is the opinion that light railways will never suffice for continuous traffic. That opinion is based on certain cases in the Colonies, where it was thought fit to adopt a light rail weighing about 18 to 27 lbs. per yard, but keeping to the old normal gauge. It is nevertheless evident that it is impossible to construct cheap railways on the normal gauge system, as the maintenance of such would-be light railways is far more costly in proportion than that of standard railways.

The narrow gauge is altogether in its right place in countries where, as notably in the case of the Colonies, the traffic is not sufficient to warrant capitalising the expense of constructing a normal-gauge railway.

Very recently the Eastern Railway Company of the Province of Buenos Ayres have adopted the narrow gauge for connecting two of their stations, the gauge being 24 ins. and the weight of the rails

19 lbs. per yard. They have constructed altogether six miles of narrow-gauge road, with a rolling stock of thirty passenger carriages and goods trucks and two engines, at a net cost price of £7,500, engines included. This line works as regularly as the main line with which it is connected. The composite carriages in use are shown in Figs. 25 and 26, Plate 13, and leave nothing to be desired with regard to their appearance and the comfort they offer. Third-class carriages, covered and open, and covered goods wagons, are also employed.

All these carriages are constructed according to the model of those on the Festiniog Railway. The engines weigh 4 tons, and run at 12½ miles per hour for express trains with a live load of 16 tons; while for goods trains carrying 35 tons the rate is 7½ miles an hour.

Another purpose for which the narrow-gauge road is of the highest importance in colonial commerce is the transport of sugar cane. There are two systems in use for the service of sugar plantations:

1. Traction by horses, mules, or oxen.
2. Traction by steam-engine.

In the former case, the narrow gauge of 20 ins. with 14 lbs. rails is used, with platform trucks and iron tipping cradles about 5 ft. long and 4 ft. wide, as shown in Figs. 27 and 28, Plate 13. The use of these wagons is particularly advantageous for clearing away the sugar cane from the fields, because, as the crop to be carried off is followed by another harvest, it is important to prevent the injury done by the wheels of heavily laden wagons. The cradles may be made to contain as much as 1300 lbs. of cane for animal traction, and 2000 lbs. for steam traction; the cane is cut up into pieces of 4 to 5 ft. length, which are laid transversely across the cradle. In those colonies where the cane is not cut up into pieces, long platform wagons are used, made entirely of metal, and on eight wheels, in which the cane is laid longitudinally. When the traction is effected by horses or mules, a chain 14½ ft. long is used, and the animals are driven alongside the road. Oxen are harnessed to a yoke, longer by

20 to 24 ins. than the ordinary yoke, and are driven along on each side of the road. On plantations where it is desirable to have passenger carriages, or where the narrow-gauge line may come to be required for the regular transport of passengers and goods, the 20-inch line is replaced by one of 24 ins. gauge.

The transport of the refuse of sugar cane is effected by means of tilting basket-wagons, the lower part of which consists of plate iron, as in earthwork wagons, while the upper part consists of an open grating or network, offering thus a very great holding capacity without being excessively heavy. The content of these wagons is 90 cubic feet (2500 litres). To use them for the transport of earth, sand, or rubbish, the grating has merely to be taken off. The cost of one mile of the 20-inch road, with 14 lbs. rails, thirty basket wagons, and accessories for the transport of sugar cane, is £700; and the total weight of this plant amounts to 35 tons.

In cases where the transport of sugar cane has to be effected by steam power, the most suitable width of road is 24 ins., with 19 lbs. rails; and this line should be laid down and ballasted most carefully.

Owing to the great lightness of the portable railways, and the facility with which they can be worked, the attention of explorers has repeatedly been attracted by them. The expedition of the Ogowé in October 1880, that of the Upper Congo in November 1881, and the Congo mission under Savorgnan de Brazza, have all made use of the Decauville narrow-gauge railway system.

During these expeditions to Central Africa, one of the greatest obstacles to be surmounted was the transport of boats, where the rivers ceased to be navigable; for it was then necessary to employ a great number of negroes for carrying both the boats and the luggage. The explorers were, more or less, left to the mercy of the natives, and but very slow progress could be made.

On returning from one of these expeditions in Africa, Dr. Balay and M. Mizon consulted the author as to whether the narrow-gauge line might not be profitably adapted for the next expedition. He accordingly proposed to transport their boats, without either taking

them to pieces or unloading them, by placing them on two pivot trollies, in the same manner as guns are transported in fortifications and in the field. The first experiments were made at Petit-Bourg with a pleasure yacht. The hull, weighing 4 tons, was placed on two gun-trollies, and was moved about easily across country by means of a portable line of 20 ins. gauge, with 14 lbs. rails. The length of the hull was about 45 ft., depth 6 ft. 7 ins., and breadth of beam 8 ft. 2 ins., that is to say, five times the width of the narrow gauge: notwithstanding which the wheels never left the rails. The sections of line were taken up and replaced as the boat advanced, and a speed of $\frac{5}{8}$ mile per hour was attained. Dr. Balay and M. Mizon declared that this result far exceeded their hopes, because during their last voyage the passage of the rapids had sometimes required a whole week for one kilometre ($\frac{5}{8}$ mile), and they had considered themselves very lucky indeed if they could attain a speed of one kilometre per day. The same narrow-gauge system has since been three times adopted by African explorers, on which occasions it was found that the 20-inch line, with 9 lbs. or 14 lbs. rails, was the most suitable for scientific expeditions of this nature.

The trucks used are of the kind usually employed for military purposes, with wheels, axles, and pivot bearings of steel; on being dismounted, the bodies of the two trucks form a chest, which is bolted together and contains the wheels, axles, and other accessories. The total weight of the 135 yards of road used by Dr. Balay and M. Mizon during their first voyage was 2900 lbs., and the wagons weighed 5000 lbs. Hence the expedition had to carry a supplementary weight of $3\frac{1}{2}$ tons; but at any moment the material forming this burden became the means of transporting, in its turn, seven boats, representing a total weight of 20 tons.

It is impossible to enumerate in this paper all the various kinds of wagons and trucks suitable for the service of iron works, ship yards, mines, quarries, forests, and many other kinds of works; and the author has therefore limited himself to mentioning only a few instances which suffice to show that the narrow gauge can be

applied to works of the most varied nature and under the most adverse circumstances possible.

It remains only to mention the various accessories which have been invented for the purpose of completing the system. They are illustrated in Figs. 7 to 13, Plates 5 and 6, and consist of off-railers, crossings, turntables, &c.

The off-railer, Fig. 7, Plate 5, is used for establishing a portable line, at any point, diverging to the right or left of a permanent line, and for transferring traffic to it without interruption. It consists of a miniature inclined plane, of the same height at one end as the rail, tapering off regularly by degrees towards the other end. It is only necessary to place the off-railer (which, like all the lengths of rail of this system, forms but one piece with its sleepers and fish-plates) on the top of the fixed line, adding a curve in the direction in which it is intended to go, and to push the wagons up the off-railer, when they will leave the fixed line and pass on to the new track.

The switches consist of a rail-end 4 ft. long, which serves as a movable tongue, placed in front of a complete crossing, the rails of which have a radius of 4, 6, or 8 metres; a push with the foot suffices to alter the switch. There are four different models of crossings constructed for each radius, namely:

1. For two curves with symmetrical divergence.
2. For a curve to the right and a straight track, Fig. 8, Plate 5.
3. For a curve to the left and a straight track, Fig. 9.
4. For a meeting of three tracks.

When a fixed line is used, it is better to replace the movable switch by a fixed cast-iron switch, Fig. 8, Plate 5, and to let the men who push the wagons turn them in the direction required. Planed switch-tongues are also used, Fig. 9, having the shape of those employed on the normal tracks, especially for the passage of small engines; in this case the switches are completed by the application of a hand-lever, Fig. 10.

The portable turntable, Figs. 11 and 12, Plate 6, consists of two faced plates, laid one over the other, the lower of thick sheet-iron, and the upper of cast-iron. The sheet-iron plate is fitted with a pivot, round which the cast-iron plate turns. The top plates may

either be smooth, Fig. 11, or grooved for the wheels, Fig. 12; the former are used chiefly when it is required to turn wagons or trucks of light burden, or, in the case of earthworks, for trucks of moderate weight. These turntables are quite portable; their weight for the 16 ins. gauge does not exceed 200 lbs. For engineering works a turntable plate with variable width of track has been designed, admitting of different tracks being used over the same turntable.

For permanent lines, and to carry heavy loads, turntables with a cast-iron box are required, constructed on the principle of ordinary railway turntables. The heaviest wagons may be placed on these box turntables, without any portion suffering damage or disturbing the level of the ground. In the case of coal mines, paper-mills, cow-houses, &c., with permanent lines, fixed or dead plates are employed, Fig. 13, Plate 6. Such plates need only be applied where the line is always wet, or in workshops where the use of turntables is not of frequent occurrence. The fixed plate is most useful in farmers' stables, as it does not present any projection which might hurt the feet of the cattle, and it is easy to clean.

The only accident that can happen to the track is the breaking of a fish-plate. It often happens that the fish-plates get twisted, owing to rough handling on the part of the men, and break in the act of being straightened. In order in such cases to facilitate the repairs as much as possible, the fish-plates are not riveted by machine, but by hand; and it is only necessary to cut the rivets with which the fish-plate is fastened, and remove it if broken. A drill passed through the two holes of the rail removes all burrs that may be in the way of the new rivet. No vices are required for this operation; the track to be repaired is held by two men at a height of about 28 ins. from the ground, care being taken to let the end under repair rest on a portable anvil, which is furnished with the necessary appliances. The two fish-plates are put in their place at the same time, and the second rivet is held in place with one finger, while the first is being riveted with the hammer; if not so held in its place it may be impossible to put the second rivet in afterwards, as the blows of the hammer often cause the fish-plate to shift, and the holes in the rail are pierced with great accuracy to

prevent there being too much clearance. No other accidents need be feared with this line; and the breakage above described can easily be repaired in a few minutes without requiring any skilled workman.

The narrow-gauge system, which has recently undergone so great a development on the Continent, where its usefulness and the facility of its application to the most varied purposes have been demonstrated, has not yet met in England with the same universal acceptance; and those Members of the Institution who last year visited Belgium were perhaps surprised to see so large a number of portable railways employed for agricultural and building purposes and for contractors' works. But in the hands of so practical a people it may be expected that the portable narrow-gauge railway will soon be applied here to even a larger number of purposes than elsewhere.

Discussion.

Mr. James Kerr said he had listened to the paper with great interest; and to M. Decauville certainly belonged the credit of first using a portable track for agricultural purposes. The plan was now so extended that the variety of purposes to which portable railways and light narrow-gauge railways could be applied was innumerable.

In regard to the connection of the rails and sleepers he differed from the paper, in which riveting was mentioned as opposed to the use of bolts and clips. There were several makers, Messrs. John Fowler & Co. and others, as well as himself, who used sleepers that were bolted to the rails. He believed it was considered by the author that the saving effected in freight, by shipping the sleepers separate from

the rails, was equalised by the extra cost of skilled labour to put them together when they arrived at their destination in a distant land. But the separate sleepers were so constructed that when they left the works they were perfect to gauge, and required no skilled labour to put them together at their destination.

Furthermore the author's inseparable sleepers did not project outside the rails, and the corrugation was made in the centre of the sleeper. The weight would naturally fall on the rail at the end of the sleeper; and under the base of the rail there was simply a flat piece of steel, barely three inches long at the end of the sleeper, projecting beyond the corrugated central portion. It would have been better he considered if the sleeper had been made trough-shape or with a double corrugation running from end to end, with the sleepers longer than the gauge of the railway. Such sleepers must necessarily be stronger, besides having a greater bearing surface; therefore with the same weight of rail the railway would carry a greater weight. With the sleepers projecting beyond the gauge of the railway the extra weight for portable purposes was very slight; for two men were required to carry a weight of 100 to 120 lbs., instead of only one as stated in the paper, especially in the case of unskilled labour abroad, such as was found in the West Indies; so that 4 or 5 lbs. extra was not much when divided between two men. Most of the makers in England adopted sleepers exceeding in length the gauge of the railway.

As to the method of rail-joints used by himself on lines for agricultural purposes, it was a very great advantage to have the joints so that there were no loose parts, because with unskilled labour any loose parts were very easily laid aside and lost. The result of his own latest experience had been the joint shown in Figs. 31 to 34, Plate 14, which was made by means of a projecting shoe-plate riveted on one end of the rail, and having a jaw or clip formed on the projecting portion, but with a space left between the rail end and the jaw or clip, so that any obstacle which might otherwise interfere with the rail ends coming together could be easily cleared away. But when such railways were laid as permanent narrow-gauge railways, there was no joint to surpass the

ordinary fish-joint with four fish-bolts. In the fish-joint mentioned in the paper and shown in Fig. 5, Plate 4, the fish-plates projected only $1\frac{1}{4}$ inch beyond the rail end, with only the same amount of projection for the sole-plate, and a single bolt to put the joint together. For locomotive power such a joint was not sufficiently strong, and a joint sleeper would then be better; but still the ordinary fish-plate joint was the best to be adopted, if made strong enough. He was at present constructing a light railway, 70 miles long, in India, with 20-lbs. rails laid on the trough-formed sleeper shown in Figs. 29 and 33, Plate 14, which imbedded itself very much better in the ballast than a corrugated sleeper; the gauge was 2 ft. 6 ins. This railway was in the upper portion of the Bombay presidency, and was to carry wheat and passengers, and the government had allowed it to be laid along the side of the high road. Similar railways were contemplated elsewhere in India; but it was found with such extreme lightness the safest principle was to follow as far as possible the same mode of construction as with the permanent heavier and wider-gauge railways.

Mr. J. W. HARTLEY said he also, as a constructor of narrow-gauge plant, had listened to the paper with great interest. The author had certainly been a pioneer to English inventors; and he should have been glad therefore if the paper had gone rather more fully into details, because after all a portable railway was a business of detail. The advantages of the portable system were well known to all mechanical engineers, and what they really wished to know was which was the best system in detail. With regard to the sleepers, although it was stated in the paper that they did not project beyond the rails, yet it appeared that when the author used bowl sleepers of dished steel for soft ground he added the bowls outside the rails: instead of carrying out his own rule by putting them inside the rails, as would have been expected. The rail fastening used by the author he considered was very weak, having only the two projecting fish-plates and the sole-plate. In some of the railway work which he had seen so constructed, the fish-plates were so extremely light that he should say a navvy, with a pair of ordinarily heavy boots, would

be able to kick them off quite easily. He was certain they were not calculated to stand the rough work with which they would constantly be used upon contractors' lines. In comparison with the fish-plate there was no doubt that one of the best portable joints was a mere shoe, which was fixed round and projected beyond one end of each rail, and into which the next rail end was slipped; it was put on the right-hand rail of each section, so that the sections were reversible end for end. There was no danger of that shoe being broken off, as there was in the case of almost every other system; it had been well tested for a great number of years.

With regard to wagons, he should have been glad if the author had shown a little more of the details of the work; for instance, the best method of fastening the wheels on the axles, which was a source of great difficulty to every contractor; also the best form of coupling and of the central buffer. In ordinary railway work it was of course the practice to carry the side beams forward and make buffers of them; but in narrow-gauge work it was usual merely to fix a central bent plate in front of each end of the wagon. That was rather objectionable, because then the buffing, instead of coming on the strongest points, simply served to knock the frame to pieces. He should like to have seen also a detail of the author's axle-boxes, because that was another source of wear and tear; and such a detail would have been a great deal more serviceable to himself than a number of general illustrations.

With regard to the points and crossings shown in Fig. 8, Plate 5, there did not seem to him to be any support at all for the crossing. Moreover in this, as in several other portable railways, he believed a cast-iron crossing was used; but he thought that, excepting at collieries or places of that sort, it was now generally considered that a crossing made out of the rails themselves was very much better; the other rails could be fished up to it, and it made a very much stronger job than a cast-iron crossing. In addition to this, as everyone knew who had travelled by ordinary railways with the cast-iron block crossings, whenever the train came to such a crossing it was like a general blow on the wheels, which was very distinctly felt by everyone in the train. For that reason he thought

manufactured crossings were very much better than cast-iron crossings. Then again in reference to the points, he thought fixed points in portable railways were not a very good thing, because supposing in Fig. 8 it were wanted to turn to the right with a train of wagons drawn by a horse, it was clearly impracticable to have a man to stand at the fixed switch and shoulder every truck as it came along. It was far better to have a movable switch so as to divert the wagons in the proper manner. A shifting rail, such as the author used instead of a switch, was a very temporary kind of expedient; it did very well so long as the trucks were running forwards off the points; but if they were running backwards on to the facing points of the switch, and if it happened that the switch tongue was not exactly in the right place, the trucks would naturally be thrown off the line. There was also what was called in the paper an off-railer, Fig. 7, Plate 5, to which was attached a curve in order to make a temporary connection with a branch line. For such a case as this he had himself always constructed a special curve attached to the inclined plane, which was constructed with sleepers of such a length that they went across and rested upon both lines. It would be readily understood that it was not an easy method to attach an ordinary curve to inclined planes like the off-railer in Fig. 7, because the curve had to be packed up where it crossed over the inside rail. It was far better he thought to construct a special curve and attach it to the inclined planes.

With regard to the turn-tables, he found it an advantage to dish the lower plate, making it higher in the centre, which also gave it additional strength. A flat plate did not take the bearing very well, because, if much weight were put on it, it naturally sank in the centre, the bearing came on the outside, and the table consequently required much more force to turn it than if the plate were dished upwards in the middle, giving it greater stiffness.

Mr. E. Hamer Carbutt, M.P., said, although no doubt great credit was due to the author for introducing the portable railway, he thought the greatest credit was due to Mr. Ramsbottom, who for many years had utilised locomotives on a very narrow-gauge line in

the Crewe works for transferring the Bessemer steel from one department to another; and any one who had visited Crewe and had seen those locomotives running about the works with $1\frac{1}{2}$ ton of steel or a finished axle or any other materials, must have been thoroughly satisfied that Mr. Ramsbottom's system of work played an important part in reducing the expenses.

He was very glad this paper had been brought forward, because his own impression was that military men ought to adopt these portable railways very much more than they had done. There was a parliamentary committee sitting at the present time to enquire into the question of transport. Hitherto in nearly every war transport had broken down; and during the last Indian war he believed the transport broke down most signally, and an enormous sum had had to be paid for camels, mules, and different animals, which did very little work; and if the government could be induced to take up a portable railway, they would thereby be able to save a great deal of money. In the discussion on whether this committee should be appointed, he had pointed out the mistake that had been made in the Egyptian war, in sending out four or five large locomotives, several first, second, and third-class carriages, and several wagons; and when these got to Egypt, there had not been the slightest arrangement made for taking them out of the ship, and not a single locomotive or carriage or any material whatever was taken out and landed. If a system of portable railway of this kind had been adopted in conjunction with long gantries made of light girders, it would have been easy to take the material off a ship lying in the Suez Canal; the locomotives themselves could thereby have been run along the gantry over the side of the ship, and by laying the rails along the decks the locomotives would have been able to unload the ship; whereas there were above a hundred ships waiting to be unloaded, and there were no means of unloading them. If by a small expenditure and a little engineering knowledge a system of this kind could have been adopted, whereby the locomotives could be run over the ship's side in that way, then the material could have been run inland and the line laid at the rate of a mile a day; and a large amount of trouble might thereby have been saved to the troops.

Whatever glory might come to the military authorities for having vanquished the Egyptians in the way they did, his own impression was that, if they had had to meet foes of equal courage with their own, they might have been fighting there still in the north of Egypt, and the question of transport would have been a very serious one. Now that a society like the Institution of Mechanical Engineers had had a subject of this sort brought before them, he hoped the attention of the military engineers would be called to it, and that the makers of these different kinds of railways would take care that some one should represent their views before the present committee sitting in the House of Commons on the subject of transport. He hoped they might ask their friend Mr. Ramsbottom to say a few words on the subject, for there was no man better able to speak upon it than he.

Mr. John Ramsbottom feared that on this question he was slightly out of court. He had put down at the Crewe Works about twenty years ago a railway of 18-inch gauge, with 22 or 23 lbs. rails, but it was not a portable railway, it was a permanent one. It had done very useful work ever since that time. It was laid down alongside the ordinary 4 ft. 8½ ins. gauge. He had adopted the narrow gauge so that no turntables need be required, the workshops being entered by sharp curves, one of which was only 13 or 14 ft. radius. A locomotive was employed upon the line; and frequently trains weighing 10 or 15 tons, and in some cases as much as 20 tons were run along it. From that time to this its working had been he believed eminently satisfactory in every way; so much so that, having been applied first to the old works, it had been adopted also in the new works when they were put down, and it was now very satisfactorily employed. The cost of the whole line was a mere bagatelle. There were now some six or eight locomotives employed upon it, and trucks adapted for moving almost everything about the place, including in some cases heavy grindstones as large as 6 or 7 ft. in diameter.

Mr. Charles Cochrane, referring to the subject of sleepers, believed that under ordinary conditions of passenger and goods

traffic the importance of projecting sleepers was fully established; but in justice to the author of the paper, and in his absence, he wished to correct an erroneous inference that had been drawn from the paper as to the reason of the adoption of the bowl sleepers shown in Figs. 3 and 4, Plate 4. In regard to these it was distinctly stated in the paper (p. 128) that it was only in case the ground was too soft that the author had recourse to these bowl sleepers of dished steel, and that the necessity for using these was but seldom experienced. He wished to call attention to this, because the author was not present to correct the misconception himself.

On another question which had been raised—namely that of fixed points—he thought it was a well known fact that it was not the object of these portable lines to obtain high speeds; and the greatest speed referred to in the paper was one of 40 miles in five hours in Tunis, or only 8 miles an hour. All engineers were fully aware that they did not have movable switches on ordinary tramroads; and that the fixed points were admirably adapted for the purpose for which they were used on tramways, where by a slight side pull of the horse the carriages were retained on the tracks.

M. C. L. FLATEAU, as the manager of M. Decauville's branch works at Corbeil, Paris, expressed the regret of the author at being unable to be present. He exhibited an extensive series of photographs, showing the application of the portable railway and plant to many of the purposes described in the paper.

In regard to the alleged disadvantage of the dished sleepers, which it was supposed were so weak that there would be a risk of the line losing its gauge, it must be remembered that, according to the purpose for which the line was designed, the thickness of metal in the sleepers was changed. If for instance the line was wanted for farming purposes, the sleepers were made much thinner than if it was for heavy earthworks or for a tunnel. With the proper thickness of metal in the sleepers there was no reason for fearing that these dished sleepers would get bent at the places where the rails rested on them. He had had occasion himself some days ago to see a severe practical trial made of the projecting sleepers and the

non-projecting sleepers. A commission having been deputed to make some experiments on M. Decauville's grounds had asked him to plough up a short length of the ground over which the portable railway lay. It had accordingly been ploughed up, and the line was then laid down again over the ploughed ground, without the fish-plates being even bolted together, and a 4-ton locomotive was run over it, together with several trucks loaded to 7 tons each; and after this experiment had been continued all day the gauge was specially examined by the commissioners, who could not find any place where the non-projecting dished sleepers had given way.

With regard to the shoe-plate which had been described in the discussion, for joining the rail-ends by means of a clip or jaw, as far as his own experience went he did not think it was so very practicable a plan as had been represented; because if that shoe-plate were lying for any length of time on the ground it would of course get rusty, and no doubt some difficulty would be experienced in undoing the joint, and it would certainly be necessary to use tools to undo it; but when it came to putting the joint together again, it would be found quite an impossibility to get the rail-end into the jaw on account of the rust. The ordinary fish-plates shown in Fig. 5, Plate 4, which had been spoken of as not being strong enough for a locomotive line, were not used for such cases; on lines to be worked by locomotives stronger fish-plates were used, which were very similar to those used on permanent narrow-gauge railways.

The crossing shown in Fig. 8, Plate 5, which had been alluded to as being made of cast-iron, was not made of cast-iron at all, but was formed of the ends of the rails themselves; it was nothing else than four rails meeting together, and those rails which represented the curve were bent. The fixed cast-iron switch shown in Fig. 8 was used only for permanent lines. When it came to lines which were very often shifted from one place to another, as for instance in earthworks, there the switch was nothing else than a simple piece of rail about 4 feet long, which could be moved right or left by foot or by a stick or a bar of iron.

As regarded the coupling of the trucks, the paper was only of a general character, and it could hardly be expected therefore that all

the details should be mentioned. For ordinary work, such as farming purposes, several kinds of buffers were adopted. For earthworks the central dead buffer shown in Figs. 17 and 18, Plate 9, was used, and it did very well so long as there was but little shock, as was the case with the tipping boxes, Plate 9; but when it came to heavy earthworks, where the trucks were drawn by horses, then a dead buffer like that shown in Plate 9 was used on one side of the wagon, and on the other side a buffer with a spring, the object being to prevent the wagons from coming off the rails. Of course in wagons intended for conveying soldiers and for other similar purposes, all the buffers were made with a spiral spring inside.

As to the turntables, he had himself made many experiments with them, and he had been present many times at experiments which had been made with them for the transport of guns. He had taken great interest in the transport of war material, because he always considered that this portable railway was of the greatest use not only for common purposes, such as earthworks, farming, and so on, but also for the transport of very heavy cannon where great quickness and great facility in using the plant were necessary. In his own experiments, employing unskilled workmen taken from the fields, a gun weighing $4\frac{1}{2}$ tons had been turned end for end on the turntable, that is to say first the breech and then the muzzle; and this had been done with the greatest facility. In some other experiments at which he had been present, very heavy pieces had to be carried over ditches 5 to 8 feet wide, where it seemed that a bridge would be necessary; and he had himself made trial of putting a simple straight section of the railway over such a ditch, with a plank alongside for the men who drew the gun to go over; and he had found that not only did the rails not bend very much, but no rivet had given way, and the length of railway across the ditch had remained perfectly safe under the load.

Mr. Ernest Spon, as also representing the author of the paper, said he had experience with systems of light railway other than that described in the paper, and the main trouble he had himself always found in these very light lines of railway was in maintaining the

gauge. On such lines this was far more important he held than it was upon heavier and larger lines. This point had been kept in view all through by the author, who maintained that the portable railway must leave the workshop with its gauge already established, and must never be altered by the man who was going to use it. Another thing aimed at had been to make the portable railway so cheap as to come within the means of an ordinary farmer.

With respect to the enquiry which had been made about the axleboxes used by the author, he might explain that they were made with an oil reservoir in the lower portion, having a sponge in it against which the underside of the journal rubbed. This axle-box afforded therefore nearly the same lubrication as had been indicated as the best in the recent friction experiments conducted by the Institution for determining the most advantageous method of lubrication to be adopted in future.

In reference to the remark that it appeared from the paper to be merely a matter of economy in transport to make the rails wholly rigid with the sleepers, instead of making them capable of being detached,—he thought it would be seen from page 127 that this was by no means the author's view, but that the rigid maintenance of the gauge was the first and paramount principle in his system.

Mr. KERR explained, with regard to the shoe-plate which he used for the rail joints, that the jaw was made very free at the mouth. It widened out at the front end, so as to give the rail a lead in; and it was made sufficiently easy for the rail end not to be perfectly tight in it, so that the rail might be inserted freely and drawn out freely, and so that no corrosion might affect it.

The PRESIDENT said it was now their pleasing duty to tender a vote of thanks to the author for his paper; and at the same time he would express on their behalf the obligation they were under to M. Flateau for the admirable manner in which he had addressed them in English in reply to the criticisms that had been offered in the discussion.

ON THE MOSCROP ENGINE RECORDER, AND THE KNOWLES SUPPLEMENTARY GOVERNOR.

By Mr. MICHAEL LONGRIDGE, of Manchester.

The object of this paper is to describe two instruments which are attracting much attention among the cotton spinners of Lancashire. The first, "Moscrop's Engine Recorder," is an apparatus for measuring and permanently recording the angular velocity of the main shaft of a steam engine, or of any other shaft to which it may be connected. The second, "Knowles' Supplementary Governor," is a contrivance for regulating the position of the throttle or expansion valve, in such a manner as to maintain a constant speed under considerable variations of load and boiler pressure. The author purposes in each case to explain briefly the causes which led to the invention of the apparatus, then to describe it, and lastly to illustrate its working by examples.

I. Moscrop Engine Recorder.

Perhaps some of the most difficult cases an engineer has to deal with are those of "unsteady turning," as it is called; that is of variations, periodic or anomalous, in the speed of a steam engine or of the machinery driven by it. In such cases it is easy to proceed tentatively, by adding weight to the fly-wheel, putting in stiffer shafts and pedestals, trying different types of governors or cut-off motions, and the like. This however is not engineering, but empiricism: empiricism too of a costly kind, as many a cotton spinner who has tried it, and perhaps been none the better for it, could be found to testify; for unfortunately such methods of procedure are by no means rare. Nor must they be condemned too harshly; for the difficulty of making such a scientific diagnosis, as alone will indicate the proper remedy to be applied, is often very great, and sometimes insuperable.

To proceed by calculation is tedious, and frequently delusive; for in many cases the necessary data are not obtainable with any accuracy. The indicator diagrams, when properly transformed, will give the tangential pressures on the crank pin, and the power to be absorbed and returned by the fly-wheel during the revolution. But the capacity of the fly-wheel for absorbing power is often difficult to ascertain, and unless this be known the maximum and minimum angular velocities cannot be deduced; even if the weight and moment of inertia of the wheel be given, the result is not correct, but must be modified according to the weights and speeds of the reciprocating and unbalanced parts. Again, if we suspect the governor to be in fault, the results of calculation cannot always be relied on; for friction, the construction of the throttle valve or expansion gear, and even the regulating power of the fly-wheel, may so influence the action as to make it differ widely from what it should be.* By proceeding in this way therefore, we are apt to feel, when all is done, that we have obtained rather an indication than an exact knowledge of the course to take; and it was the need of some more ready and certain method of solving problems of this class which led to the invention that is now to be described.

The instrument consists essentially of a clock to tell the time, and to give a uniform motion to a paper tape; of a centrifugal governor, actuated by a band from the main shaft of the engine, or from any other shaft of which the motion is to be recorded; and of a marker connected with the governor by levers, in such a way that its position upon the paper tape depends on the angular velocity of the governor at the moment.

The way in which the several parts are combined will be most easily understood by reference to Figs. 1 and 2, Plates 15 and 16. Here C is the clock controlled by a pendulum and anchor escapement; T is the paper tape drawn from the reel E, passing over the recording drum A, and coiled below upon the large drum D, which revolves under the action of the weight W. The reel E is carried on hook

* On the question of variations in the governor, see Mr. Wilson Hartnell's paper, Proceedings 1882, p. 408.

bearings to facilitate replacement. The recording drum A is connected with the clock-work by spur gearing, so proportioned as to give it an angular velocity of one-third of a revolution per hour. Round its circumference are three equidistant pairs of projections I, Fig. 3, which gear into equidistant pairs of holes punched in the margins of the tape, Fig. 6, Plate 17, and cause the tape to move at the same speed as the drum. These projections are so arranged that one pair comes to the top of the drum at the beginning of every hour. The large drum D, Fig. 1, is mounted loosely upon the shaft F, but is connected with it by a ratchet-wheel and pawl J, so that the shaft may be turned backwards, to wind on the cord when the weight W runs down, without disturbing the drum, which is then held by another pawl and ratchet-wheel K at its opposite end.

The centrifugal governor G is carried by the vertical shaft H, Fig. 1, Plate 15, and is driven by a band which passes round the pulley O at bottom, under the guide pulleys Q, and round the shaft of which the motion is to be recorded. The arms of the governor are furnished with cantilevers V, having smooth upper surfaces upon which rests the crosshead U; and the distance between the points of contact is so arranged that the sleeve attached to the crosshead U rises or falls on the shaft H through equal distances for equal increments or decrements of angular velocity. This sleeve gives motion to the bell-crank lever L, which is kept in contact with the flange N by the spring S; and the bell-crank carries the rod R, which in its turn holds the marker M.

The marker is illustrated in Fig. 4, Plate 16. It consists of a marking wheel M, a pair of brake discs B, and an inking pad P. When the rod R moves forwards towards the clock-face, the wheel M revolves, receiving the ink on its upper edge from the pad P, and discharging it from its lower edge upon the tape T; when it moves in the opposite direction, the brake discs B prevent the wheel from turning, and it is dragged backwards across the paper, which then serves as a scraper to keep the marking edge clean. The ink is made from an aniline dye, mixed with glycerine to prevent evaporation.

The paper tape, as seen in Fig. 6, Plate 17, is ruled beforehand both longitudinally and transversely; each of the longitudinal rulings

corresponds with an increase or decrease of $4\frac{1}{2}$ per cent. in the angular velocity, and each of the transverse lines shows an interval of five minutes. The commencement of each hour is marked, as already explained, by the transverse lines joining the pairs of holes in the margins of the tape.

When the recorder is in use, the length of the carrier R, Fig. 1, Plate 15, is so adjusted by a set-screw that the marker M rests upon the longitudinal centre-line CC on the paper, Fig. 6, when the engine is running at its normal speed; and so long as this speed is maintained the marker will not quit this line, and the diagram produced will be a straight longitudinal line coinciding with CC.

Such a diagram would be the standard of perfection, could it be obtained; for it would indicate an absolutely uniform velocity throughout the time of running. Owing however to the variation in the tangential component of the pressure on the crank-pin of the engine, the angular velocity of the shaft is never uniform; but varies between maxima and minima values, depending upon the point of cut-off, upon the weights of the fly-wheel and of the reciprocating and unbalanced parts, upon the perfection of the governor, and upon other causes.

If during any stroke the mean speed be equal to the normal speed of revolution, the marker will move from some point below the centre-line CC to an equal distance above it, and will return to its initial position, ruling on the paper a transverse line of which the length above and below CC measures the excess and deficiency of speed.

If on the contrary the mean speed during any stroke exceed or fall below the normal speed, the whole transverse line will be displaced bodily upwards or downwards. Consequently the position of the centre line or axis, of the band produced upon the paper by consecutive strokes, will indicate the variation of the mean speed during any interval of time; and its parallelism or otherwise with the line CC will show the regularity of the speed and the efficiency of the governor. Moreover the position of the diagram with reference to the transverse rulings on the tape records the times of starting and stopping, the duration of the run, and the hour and minute when any irregularity in the motion may have occurred.

The tape thus becomes a permanent record of the performance of the engine; and when taken off the drum D, cut into lengths, and pasted into a book, can be referred to at any time afterwards. By way of illustration, copies of some of the diagrams made by engines in Lancashire are given. Let us see what they have to tell.

The diagram, Fig. 9, Plate 18, was taken from a "McNaughted" beam-engine in a cotton mill, cylinders 36 ins. and 42 ins. diameter, strokes of pistons 3 ft. 6 ins. and 7 ft., revolutions $28\frac{1}{2}$ per minute; I.H.P. about 410, fly-wheel 22 ft. 3 ins. diameter and 22 tons weight. Here it will be seen that in the morning, when the machinery was stiff from standing during the night, the speed of revolution varied at times no less than 23 per cent., and not less than $13\frac{1}{2}$ per cent. at any time. The cause was evidently insufficient fly-wheel power. By increasing the speed to 33 revolutions, and adding 10 tons to the wheel, a marked improvement was effected, the variation being reduced considerably, as shown in Fig. 10.

In contrast to the last example, Fig. 11, Plate 18, is given. It was taken from a Corliss engine with a 40-inch cylinder and 8 ft. stroke, running $46\frac{1}{2}$ revs. per min. This engine develops 800 I.H.P., the power being transmitted by a belt drum 30 ft. diameter and 70 tons weight. This example and Fig. 9 are about the best and worst which the author has met with as regards fly-wheel power.

To illustrate the influence of the governor on the regularity of the motion, Figs. 7 and 8, Plate 17, are given. They were produced by a pair of "McNaughted" beam-engines, coupled by the main shaft and with the cranks set at right-angles. The cylinders are 44 ins. and 63 ins. diameter, and the strokes of the pistons 4 ft. and 8 ft. The power, 1550 I.H.P., is transmitted through a spur fly-wheel, 24 ft. diameter at the pitch line and weighing 70 tons. When Fig. 7 was taken, the speed was regulated by a common slow-speed Watt governor and an equilibrium throttle-valve. As far as could be judged by counting the revolutions, the engines appeared to be running regularly enough: but the recorder when connected told a different tale, and at the same time indicated the proper remedy, namely a better governor. Accordingly Mr. Knowles' supplementary governor was put on, with the result shown by Fig. 8, which proves

that the variation in the speed has been reduced more than one-half.

Fig. 12, Plate 19, was taken from a Corliss engine, cylinder 52 ins. diameter, stroke 6 ft., speed 60 revs. per min., with a belt drum 75 tons weight, running at a speed of 4400 ft. per minute. At 10.20 A.M. the speed began to slacken, and at 10.30 had fallen to 55·7 revolutions, nor was the full speed regained till 11.7, as shown in the diagram. The cause in this case was a hot main-shaft neck.

Examples might be multiplied *ad infinitum*, but the author thinks sufficient have been given to illustrate the utility of the recorder. He will however mention two other instances, in illustration of the varied uses to which the instrument may be put.

The first relates to the not uncommon occurrence of a dispute between the overlooker of a weaving shed and the engineman. The former complained of irregularity in the motion; the latter asserted stoutly, and as it afterwards appeared with truth, that his engine ran as steady as a clock. Matters got to such a pitch at last that the manager of the works declared one of the men must leave. The engineman departed, and a fresh man was engaged, who, being more shrewd than his predecessor, persuaded the manager to get a "Moscrop Clock," whereby he was able to prove that the engine was not in fault. As however the overlooker still complained, the intermediate shafts and gearing were examined, and the irregularity was traced to the slipping of some ropes on a certain drum. Thus the mystery was cleared up, and the cause of complaint removed.

The second case was a dispute between the spinners and the owners of a large cotton-mill. The question was referred to arbitration, and the arbitrator was enabled to decide it on the evidence of the recorder diagrams taken during the period of the alleged irregularity.

In conclusion it may be well to notice certain errors to which the construction of the instrument may give rise.

The first is that due to the slipping of the driving band. When the motion is taken from the main shaft of a steam-engine from 10 to 20 ins. diameter, this cannot be of any practical importance; but with a small shaft and high speed it may become considerable. In

such cases it is advisable to take the motion from a drum. In anticipation of this possibility, the first recorders were coupled up with gearing; but owing to the backlash the arrangement was abandoned in favour of the band.

The second error is that due to the momentum of the pulley O and the governor, Fig. 1, Plate 15. It no doubt affects the accuracy of the diagrams more or less in every case; and, if the speed were high, would render the indications altogether unreliable. Unfortunately too it is of the same sign, so to speak, as the error due to slip; *i.e.* it tends to diminish the amplitude of the vibrations of the marker. In the case of cotton-mill engines, where the speed in general lies between 30 and 60 revs. per min., it is probably of small amount, though its existence is evident from the backlash of the gearing mentioned in the last paragraph.

The third cause of inaccuracy is friction. Its influence is probably very slight, as the governor arms, bell-crank lever, and other parts having a free motion, are suspended on the points of conical steel spindles, so accurately fitted that a slight impulse with the finger is said to be sufficient to make the piece rotate for thirty seconds.

Lastly the diagram itself, owing to the slow motion of the tape of only 2 inches per hour, is liable to mislead, whenever the mean speed is variable, and the periods between its maxima and minima values are short. Under such circumstances the lines drawn in consecutive strokes, though perhaps individually short, are so compressed together as to appear as one long mark, and thus the flywheel seems to be less efficient than it really is. In the diagram shown in Fig. 13, Plate 19, the opener lines were obtained by accelerating the motion of the tape; as will be seen they are shorter than they appeared to be when the paper was moving at the regulation speed. To overcome this difficulty, it is proposed to add a second quick-speed drum and tape, which may be put into gear from time to time as an interpreter of the ordinary diagram.

Thus it will be seen that the recorder has its imperfections. In time no doubt they will be remedied. Meanwhile it is right to say that Mr. Moscrop is perfectly alive to them, and does not claim to

have produced an instrument of scientific accuracy, but rather one sufficiently exact for practical purposes, and sufficiently simple to guide any man of ordinary common sense. Already within two years of the invention of the recorder there are upwards of four hundred at work.

II. Knowles Supplementary Governor.

A defect common to all centrifugal governors of the ordinary type is their inability to keep the engine to a constant speed under a variable load or a fluctuating boiler-pressure.

The connections between the regulating valve and the sleeve of the governor being of invariable length, the former can only alter its position when the latter does. Consequently the opening of the regulating valve can only become larger or smaller than the normal opening, when the governor balls are revolving in a plane below or above the plane corresponding with the normal speed, that is to say when the engine is running below or above that speed.

Nor does the parabolic governor solve the problem satisfactorily; for although it is true that the valve will stand in any position when the engine is running at its normal speed, yet it is also true that any change of speed, however slight, forces the balls to one of their extreme positions; the result being that such governors are continually "hunting," as it is called, and though theoretically very good, are practically failures, unless robbed of their sensitiveness by dashpots, or by giving them considerable inertia.

To overcome the difficulty first alluded to, it has been customary to cut the rod connecting the governor with the regulating valve, and to connect the two parts by a nut with a right-and-left-hand thread, by turning which the length of the rod, and the position of the regulating valve relatively to the governor, can obviously be altered. This arrangement enables the engineman, when the load or boiler-pressure changes, to increase or diminish the opening of the valve corresponding with the normal plane of revolution of the balls; and so to keep the engine to its proper speed. It is obvious however that this contrivance can only be used when the change of load or pressure is likely to be of some duration, for the man cannot

be always handling the nut. Hence it becomes evident that some automatic mechanism is required; and such a mechanism is that of Mr. Knowles. The ordinary nut above described is fitted with a grooved pulley n, Fig. 5, Plate 16, which receives its motion from the pulley p by means of the cord c. The supplementary governor s, driven in any convenient manner from the engine, carries two friction discs d and e, which partake of both the rotary and the vertical motion of the balls. Between them, and on the same shaft as the pulley p, is placed the friction pulley f, whose diameter is less than the vertical distance between d and e.

From this description it will be seen that, while the engine maintains its normal speed or runs within any desired limits of speed (which may be fixed by properly adjusting the clearance between the discs), the friction pulley f remains at rest, and the ordinary governor g controls the engine; but if these limits be exceeded, the disc d or e will press upon f, and cause it, and through it the pulley n, to revolve in one direction or the other, thus varying the length of the rod r. This action will go on until the normal speed is again reached, when the disc d or e, as the case may be, will cease to press on f, and the rod will remain permanently lengthened or shortened, until a further change of load or boiler-pressure calls for a fresh adjustment of its length. It should also be noted that the lengthening of the rod is not performed directly by the governor balls, but by the engine, which turns the governor spindle and the discs d and e; so that the position of the balls is not at all affected (as so often is the case with light and sensitive governors) by friction of the glands, or by any jerking of the rod when the cut-off takes place. Indeed, when the engine is running at the proper speed, the governor is disconnected altogether from the regulating valve; and it acts upon it only when a change of speed requires it to act.

The same effect may be and has been produced by a single governor; but in the author's opinion the arrangements proposed for that purpose are lacking in mechanical elegance, and they are therefore not given here. The details of the supplementary governor, on the contrary, are well worked out; and this, together with the facility with which they can be modified to suit a great variety of

circumstances, and the ease with which the mechanism can be coupled to existing governors, is no doubt sufficient cause for the popularity the arrangement seems likely to attain. For in practical mechanics it is requisite not only that the principle of a machine should be correct, but also that the arrangement of the parts should be adapted to the work they have to do.

The efficiency of the supplementary governor is well shown by a comparison of the diagrams, Figs. 7 and 8, Plate 17, referred to on p. 154; but in the belief that a second example will not be out of place, the diagram Fig. 14, Plate 19, is given. It was taken from the same engine as Figs. 9 and 10, Plate 18, to which a supplementary governor was added after the fly-wheel had been loaded and the speed increased.

At 3.5 p.m. the full load was on, consisting of twenty-seven pairs of mules with preparation, the boiler-pressure being 59 lbs. per sq. inch. The pressure was then reduced to 55 lbs. at 3.20, to 50 lbs. at 3.30, and to 45 lbs. at 3.35, when the lowest grade of expansion permitted by the cut-off motion was reached. At 4 p.m. the pressure had again got up to 60 lbs., and at 4.5 the scutchers were thrown out of gear. At 4.12 four pairs of mules were taken off, and at 4.25 three pairs more; yet the axis of the diagram remained practically a straight line. It was thus proved that a reduction either of 25 per cent. in the boiler-pressure, or of about 30 per cent. in the load, caused no appreciable difference in the speed.

Discussion.

Mr. J. B. Moscrop exhibited a specimen of the engine recorder, and a large collection was shown of the recording diagrams taken by it from various engines.

Mr. William Richardson said he had not one of these recorders running, but he had seen several elsewhere, and they bore out all that had been said about them in the paper.

Mr. Lavington E. Fletcher said he had seen the recorders at work, but had not as yet had an opportunity of closely following the results obtained; but he thought the paper showed there was a good field for their operations.

Mr. James Platt had had an opportunity of seeing one of the recorders at work, and had noticed a defect in the driving. It was driven by a small belt from the fly-wheel shaft, 12 ft. away. The piecing of the belt was defective, being thicker than the body of the belt; consequently as it passed over the recorder pulley the speed of the recorder fell, and as it passed over the engine pulley the speed increased. He was therefore rather surprised to find that gearing had been abandoned for driving the instrument. This was an important matter. With a high-speed governor he had frequently seen the governor just move up and down as the piecing passed over the engine pulley or the governor pulley. There would be no difficulty, he thought, in making gearing without backlash to drive a small instrument of that kind.

Mr. William Schönheyder observed it was stated on p. 156 that the difficulty in driving the recorder with gearing arose from the backlash; and of course the backlash proved that the recorder did not work at the same speed as the engine. There was a necessity to drive it by some other means than the belt, because the belt by its elasticity would allow a certain amount of slip to take place; and although this slip could not be heard, still it was

there, even if not detected at the time. He would therefore suggest that, when the instrument was again driven by gearing, as he considered it ought to be, the backlash might be done away with by causing a certain amount of friction on the spindle of the recorder, either by a weight or by a spring, so adjusted of course that there should be no seizing; the bearing surface should be large enough, and well lubricated. He had seen ordinary governors driven by gearing, where the gearing had had to be removed on account of the noise of the backlash, because the fly-wheel was too small and lagged behind the governor during part of each revolution; the governor had a regular speed, but the engine was irregular, and therefore there was a necessary backlash; the gearing was removed, and straps were put on.

The recorder itself appeared to him an excellent apparatus, but no doubt it required improvement. In its present form he did not think it would be applicable to high-speed engines subject to quick variations in speed; for such engines certain portions of the gearing in the recorder ought to be made much lighter. The instrument exhibited he understood to be designed only for slow-moving engines, and for these it might give very accurate results.

The supplementary governor shown in the diagram, Fig. 5, Plate 16, was no doubt an excellent contrivance; but he thought there was something more in it than appeared at first glance. It seemed to him that the ordinary large governor shown at *g* in the diagram was really doing nothing whatever; it was looking on and doing nothing, while it was only the supplementary governor *s* that really did the work. It would be seen that the supplementary governor could only slightly increase or decrease in speed, and it then brought the power of the engine itself into action for adjusting the opening of the throttle-valve; in this way it no doubt regulated the engine efficiently. That being the case, he believed that the ordinary governor at *g* was not doing any good whatever. He should like to know whether the supplementary governor had been tried by itself alone. If the ordinary large governor were thrown entirely out of gear, he should expect that the engine would be regulated as well without it as with it. In other words, a large and

poorly constructed governor was the wrong thing for regulating the speed; whereas the small quick-speed governor, assisted by the engine, did the regulating effectually.

Mr. WILLIAM ANDERSON was glad to recognise in the recorder an instrument by which a very important point in the behaviour of an engine could be accurately ascertained—a point which he thought was not, as a rule, sufficiently attended to—namely the relation that existed between the degree of expansion at which an engine was working and the weight of its reciprocating parts. There was one particular speed, with relation to the weight of the reciprocating parts and the point of cut-off, at which an engine worked at its best; and the reason he thought was, as the author had intimated in p. 151 of the paper, that the surplus power, when the steam was at the highest pressure in the cylinder, was absorbed in accelerating the motion of the reciprocating parts; and the power so stored was given out again in the latter portion of the stroke, when the pressure or the work done in the cylinder was comparatively small, and when, instead of an acceleration of the reciprocating parts, there was a retardation taking place, and the power was consequently being given out to overcome the resistance. It was upon the best balance of these accelerating and retarding forces, which were continually alternating, that the smooth action of a steam engine depended. This question had been exceedingly ably treated, mathematically yet in a sufficiently simple manner, by the late Mr. George H. Strype,* the manager of the Drogheda Iron Works, who, by a mathematical calculation based on the weight of the reciprocating parts, had succeeded, among the Belfast flax spinners, in so adjusting the speed of many of their engines, or rather in so adjusting the cut-off, that he got the engines to run with the greatest possible amount of smoothness. The calculation was an exceedingly beautiful one, and it had the great merit that practice amply demonstrated its correctness. Had Mr. Strype had an apparatus like that now

* See Transactions of the Institution of Civil Engineers of Ireland, vol. vii., p. 144, 1863.

described, he might have followed the results of his arrangements with certainty. Failing such an apparatus, the efficiency of any changes could only be judged of by the ear, or by the report of those who had the control of the small machinery. By an instrument of this kind the result was exhibited unmistakeably to the eye; and the evidence so obtained was a great guide for giving to a steam engine, on strictly scientific principles, that steadiness of motion which was so important in many of the arts.

Mr. Longridge wished to call attention to a problem which had first led him to make enquiries about the Moscrop recorder. Every one who had to do with mill engines he thought must have noticed the frequent failures of the main shafts, and the lightness of the loads under which they often gave way. That fact had been brought to his own notice in a curious manner about two years ago. There was a pair of beam-engines coupled by their main shaft with the cranks at right angles: those engines had driven 1400 HP. for several years, but about two years ago the mill had been burnt down, and in consequence the load had to be reduced to 250 HP. To suit the lighter load, one of the engines was uncoupled, and the other at the right-hand end of the shaft was worked alone. The single engine had not worked more than five months before the right-hand neck of the main shaft fractured, and continued to get worse, till the engine had to be stopped. The left-hand engine was then set to work, but it had not worked very long before the left-hand neck gave way. There was thus the curious fact, that a shaft which for seven or eight years and probably a good deal longer had driven 1400 HP. without showing any sign of weakness, gave way in a few months with less than a quarter of its original load upon it. On thinking the matter over, it appeared to him that the failure was due to a torsional strain produced by the vibration of the fly-wheel upon the main shaft. A fly-wheel being a heavy body had a corresponding inertia, which prevented its changing its speed except under the influence of some extraneous force. The rotative effect of the pressure applied to the crank-pin of a steam engine varied from nothing when the crank was on the centre to a maximum

when the connecting-rod was at right-angles to the crank. When the crank was on the centre, of course the rotative velocity also was least; and when it was at right angles to the line of centres the rotative velocity was greatest; therefore in each revolution there were four points at which the rotative velocity was equal to the mean velocity of revolution. Starting from one of those points, say that in the first quadrant, the speed would begin to increase. If the fly-wheel had no weight, its angular velocity would increase at the same rate as that of the crank-shaft, but having inertia it did not do so; it lagged behind, and consequently twisted the shaft; and the angle through which the shaft was twisted increased until the resilience of the shaft was sufficient to overcome the inertia of the wheel, and cause it to swing forwards into its proper position relatively to the shaft, and then beyond it, until the resilience of the shaft pulled it up and sent it back again. In this way therefore there was a continual vibration of the wheel going on around the shaft; and since the vibration was caused by a force proportional to the angle through which the shaft was twisted, it would be seen that the motion was exactly the same as that of a common pendulum oscillating through very small angles;* and therefore that the time

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* Suppose the wheel to be twisted at most through an angle α from its natural position relatively to the shaft, and then to be let go. The equation of motion is—

$$\frac{d^2\theta}{dt^2} = \frac{\text{moment of force}}{\text{moment of inertia}}.$$

If r be the radius of the shaft, l its length from the crank to the wheel, and G the modulus of torsion of the shaft $= 0{\cdot}4$ of the modulus of elasticity, then the moment of the force is—

$$\frac{G\pi r^4\theta}{2l}.$$

And if W be the weight of the wheel, and k its radius of gyration, then the moment of inertia is—

$$\frac{W}{g}k^2.$$

And the equation of motion becomes—

$$\frac{d^2\theta}{dt^2} = -\frac{Gg\pi r^4\theta}{2lWk^2} = -A\theta.$$

of the oscillations was constant, and independent of the amplitude of oscillation. Thus it appeared that the fly-wheel oscillated about the shaft, and that the periodic time of the oscillations was constant. Also it was evident that the tangential pressure on the crank-pin attained its maximum at constant intervals, namely each time the connecting-rod became perpendicular to the crank. Now if a swing were set going, and if a push given with only the pressure of a finger were timed at the right moment, the swing could be made to go up to almost any height desired. In the same way, if the push on the crank took place at the right moment—that is, if the period of half a revolution coincided with the natural period of a double vibration of the wheel around the shaft—then every time the wheel swung forward it received a push, and the amplitude of the oscillations was increased; and it could be increased to such an extent as to destroy a shaft by that action. In the particular engine referred to, he had calculated that the period of a double oscillation of the fly-wheel would be 0·82 second. The speed of the engine was 38 revolutions per minute; therefore, when one engine only was working, the time occupied by half a revolution, or the period of the impulse, was 0·79 second, and coincided as nearly as possible with the natural period of the wheel. Of course, when the two engines

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Multiplying by $2\frac{d\theta}{dt}$ and integrating—

$$\left(\frac{d\theta}{dt}\right)^2 = -A\theta^2 + C.$$

When $\frac{d\theta}{dt} = 0$, $\theta = \alpha$ and $C = A\alpha^2$.

$$\text{Therefore } \left(\frac{d\theta}{dt}\right)^2 = A(\alpha^2 - \theta^2), \text{ and } \frac{dt}{d\theta} = -\frac{1}{\sqrt{A(\alpha^2-\theta^2)}},$$

the negative root being taken because θ diminishes as t increases.

$$\text{Therefore } t = \frac{1}{\sqrt{A}}\cos^{-1}\frac{\theta}{\alpha}, \text{ the constant being zero.}$$

If T be the time in seconds of a complete swing from one extreme position to the other, then when $t = \frac{1}{2}T$, $\theta = 0$ and $\cos^{-1}\frac{\theta}{\alpha} = \frac{\pi}{2}$.

$$\text{Therefore } T = \frac{\pi}{\sqrt{A}} = \sqrt{\frac{2\pi l W}{Gg}} \times \frac{k}{r^2} = \text{constant.}$$

were coupled with their cranks at right angles, the periods of maximum pressure occurred twice as often; so that, instead of amplifying the vibrations, every other push simply stopped them, and there was no oscillatory motion. That accounted for the shaft having stood the transmission of 1400 HP. so long as it was driven by the pair of engines at right angles. It had been in the hope of ascertaining something about these fly-wheel vibrations that he had looked into the recorder; and although of course it did not answer for that purpose, he had thought the contrivance of sufficient interest to bring before the Institution in the present paper.

With regard to the driving band mentioned by Mr. Platt, if it had been pieced with a butt joint having a cover strip over it on the outside, it would have driven smoothly enough.

In reference to the supplementary governor, of which he had been requested to add a description in the paper, its adoption did not always render the ordinary governor useless. In many cases that might be so; but if the engine had a light fly-wheel, and if the small sensitive governor were allowed to work alone, it would be acting on the throttle-valve at every revolution; whereas the ordinary heavy governor was sufficient to keep the engine regular within certain limits, and if those limits were exceeded the small supplementary governor then came into play and permanently altered the valve. The regulation however could certainly be done well with a single governor, and he had himself arranged a scheme for the purpose.

On the motion of the President a vote of thanks was passed to Mr. Longridge for his paper, and for the very lucid observations he had added.

DESCRIPTION OF THE AUTOMATIC AND EXHAUST-STEAM INJECTOR.

By Mr. A. SLATER SAVILL, of Manchester.

The almost universal adoption of the Injector for the purpose of feeding steam boilers renders any improvement in its working a matter of very general interest to engineers. A contrivance that goes far towards perfecting the action of the injector is the "split nozzle," the joint invention of Messrs. Davies, Hamer, and Metcalfe, which it is more particularly the object of the present paper to describe.

The very extensive use of the ordinary lifting injector, by which the supply of feed-water is lifted from below the level of the injector itself, has developed not only its advantages but also its disadvantages. For starting a lifting injector to work, such as that shown in Fig. 1, Plate 20, it is necessary, after turning on the water, to withdraw slightly the steam spindle A, allowing a small quantity of steam to rush through the injector. This jet clears the nozzles, and draws along with it the air from the water pipe, thereby causing a partial vacuum, which raises the feed-water into the condensing chamber or nozzle B. The steam spindle A may then be fully opened, and the injector will work, the supply of feed-water being regulated to suit. This manipulation for starting is required in all ordinary lifting injectors, although it is not so apparent in those with closed overflow; but even with these the small quantity of steam must first be turned on in order to lift the water up to the injector, and the larger quantity of steam must be admitted afterwards for the regular working. If therefore the injector happens to fail whilst working, the steam must be shut off, and the foregoing manipulation must be gone through in order to

start it to work again. In most instances this means constant attendance on the injector while at work, and forms the chief disadvantage attending its use.

Automatic Injector.—The "split nozzle," shown in Figs. 2 and 3, Plates 20 and 21, entirely obviates the above disadvantage; and its adoption renders the injector perfectly automatic in starting itself to work again after an interruption. The nozzle N is split up longitudinally for rather more than half its length from its lower extremity where the bore is smallest; the loose half forms a flap, which is hinged to the fixed half by a pin joint, from which it hangs freely. When the injector is not at work, the flap hangs open, and thus presents a very large area of passage for the exit of steam. Consequently when steam is turned on, no matter how quickly, it flows through the injector with little or no resistance, and draws along with it the air from the feed-pipe, thus lifting the water. When the water reaches the condensing chamber C, the steam is immediately condensed, a stronger vacuum is formed (exactly as in ordinary injectors), and the flap is sucked inwards, forming then to all intents and purposes an ordinary solid nozzle, through which the water is delivered into the delivery nozzle, and thence into the boiler. This simple contrivance renders the injector perfectly automatic in re-starting; for should the working fail, the flap falls open, allowing the free escape of the steam, and as a consequence the water is again lifted to the condensing chamber, a vacuum is obtained, the flap is again sucked inwards, and the instrument resumes work; all this occurs in far less time than it takes to describe.

Through the adoption therefore of the flap or split nozzle, the injector will re-start itself without manipulation; and whether placed above or below the level of the feed-water, it will immediately start work as soon as the boiler steam is turned fully on, and this may be done either quickly or slowly. The first starting is so simple that the instrument cannot be mismanaged: it is only necessary to turn on the steam and the water, either of them first, and the ease and rapidity with which the injector starts are remarkable. The great advantage of an automatic re-starting injector is

especially apparent where there is much vibration, as in the case of marine and locomotive boilers, agricultural and traction engines, &c. For marine boilers the ordinary injector has practically been a failure, owing primarily to its "giving out" or failing in a rough sea; and when this happened, it required manipulating to start it again. This difficulty is entirely removed by the split nozzle, as it immediately re-starts itself automatically.

Exhaust-Steam Injector.—The object for which the split nozzle was specially designed is for working an injector by means of exhaust steam only. With exhaust steam at atmospheric pressure, the injector is enabled by this means to feed a boiler working at 75 lbs. pressure per sq. inch; and at a higher pressure, if the feed-water be at a very low temperature. For feeding boilers at higher pressures than 75 lbs., a special contrivance, worked by live steam, is attached to the exhaust injector; the economy is then exactly the same as if this special contrivance were not used. (See discussion, pages 183–4.)

The arrangement for working with exhaust steam is shown in Figs. 5 to 8, Plate 22. In Figs. 5 and 7 are shown longitudinal sections of the split nozzle, and Figs. 6 and 8 are cross sections. In both cases the flap is shown in its two positions, namely open and shut.

The steam nozzle in the exhaust injector is of very large bore, and the spindle S inside it is a fixture. The receiving or condensing nozzle is also of a rather different make from those used for live steam. The splitting of this nozzle is carried out in exactly the same manner as previously described. There is a projection P inside the casing of the injector, which forms a stop for the flap, allowing it to open only a certain distance, as it is not necessary that the free area at any point of the nozzle should exceed the largest bore of the flap, namely that at the hinge.

The action of the exhaust injector is exactly similar to that of the automatic re-starting injector; but the exhaust injector requires to be fixed always below the level of the feed-water. The water and exhaust steam being turned on, either of them first, mingle together and escape freely through the enlarged nozzle. Condensation takes place, and a slight vacuum is formed, into which the exhaust steam

and water are drawn in quantities sufficient to form immediately a very strong vacuum. The flap is thereby sucked inwards, narrowing the nozzle to its normal size, and the injector works, delivering the water into the boiler in the ordinary way.

In the case of the exhaust injector, the property of re-starting automatically is of particular value. Most engines work irregularly, in consequence of the load being sometimes heavier and at other times lighter. When the heavy load is suddenly removed, as is often the case in saw-mills &c., the engine at once gains speed, the governor throttles or altogether shuts off the steam, and there is probably insufficient steam passing through the exhaust pipe to keep the injector supplied, so that it stops by drawing in air through the open end of the exhaust pipe; but directly the engine gets its steam again, the injector re-starts of itself. It works quite as well with the engine running empty as if heavily loaded; all it wants is steam unmixed with air.

For taking the exhaust steam to the injector, the main exhaust pipes are not tampered with in any way; a branch pipe is merely taken off at some convenient part for connecting to the injector. Fig. 4, Plate 21, shows the method of taking off the branch from some vertical portion of the main exhaust pipe; and it can be similarly taken off from a horizontal portion. It will be noticed that for the working of the injector it is not required that the main exhaust pipe should in any way be throttled; in fact the larger the pipe, the better for the injector. The other connections are similar to those of an ordinary injector.

Discussion.

The President said no one had worked more with injectors than Mr. Robinson; and he was sure the members would be glad to hear what he had to say on this paper.

Mr. John Robinson feared his knowledge of this subject was getting rather rusty. When the injector was first introduced into this country, he attended closely to all its details, and naturally took much greater interest in the progress of its development than he had done since it had become more fully matured; he had therefore to confess to a certain amount of ignorance as to some of the uses to which it had been applied. It would be observed that the paper was divided into two parts: it first described the automatic injector, and next an injector working by exhaust steam. The split nozzle or flap was stated to be a contrivance whereby the large amount of steam required in the first instance for exhausting the pipes of air, and so lifting the feed-water up to the injector, was allowed to pass without any restriction; and practice had proved that this was so. On the other hand he would call attention to a statement on p. 168, in which, when speaking of the ordinary injector described in the first instance, the author said that the manipulation necessary for starting the injector to work again when it was once stopped involved in most cases constant supervision of the injector while at work. Upon that question he should like to know what was the experience of locomotive engineers, as to how much attention was actually given by the driver of a locomotive to the ordinary injector in order to prevent its failing, in consequence of its being stopped by shunting or by any other vibration which would naturally cut off the supply of water.

The great interest of the paper seemed to him to be in regard to the use of exhaust steam for the purpose of feeding water into the boiler. For this purpose it had been stated that the injector with the split nozzle or hanging flap was very well adapted: in fact, he believed the use of exhaust steam was the object for which the split nozzle had been originally invented; and for this purpose it was

required that the injector should be placed below the level of the feed-water, which in most cases was easily accomplished. On the other hand it appeared that, with exhaust steam at atmospheric pressure, the injector would only feed a boiler up to 75 lbs. pressure. Therefore for locomotive work, in which he himself was chiefly concerned, it became unavailable, unless there were some special appliance added to it for enabling it to overcome the difficulty. On that particular point he should be glad to be further informed, because in the paper it was merely stated on p. 169 that for feeding boilers at higher pressures than 75 lbs. a special contrivance, worked by live steam, was attached to the exhaust injector; and from that statement the deduction was made that the economy was exactly the same as if this special contrivance were not used. He could infer what was meant by that statement; but in this connection he thought the author had not taken sufficient credit for the considerable economy, whether in a locomotive or in any other high-pressure engine, derived from using simply waste or exhaust steam for supplying feed-water to the boiler. That advantage of the exhaust-steam injector he thought wanted bringing out a little more strongly; and he should be glad to hear the author's views as to the economy so obtained. He concluded that the addition of live steam to the exhaust steam, where the boiler pressure was higher than 75 lbs., meant that it was then necessary to give a "fillip" to the exhaust steam by means of live steam, in order to get the necessary velocity of the current to penetrate the boiler against the pressure of the steam. Upon that point he should much like to be enlightened, as well as with respect to the actual economy in the arrangement when the waste steam only was necessary for feeding the boilers. To feed boilers above 75 lbs. pressure, it appeared a low temperature of feed-water was required, which did not often exist in this country; and of course it could readily be understood that, the lower the temperature of the feed-water, the higher might be the pressure in the boiler into which the injector had to force the water.

Mr. T. Budworth Sharp said the subject of the utilisation of exhaust steam by an injector was a particularly interesting one,

both from a scientific and from a commercial point of view, because all exhaust steam that was returned into a boiler by the injector represented an absolute gain of power, or more correctly a recovery of it in such a form that it could be used over again. An exhaust-steam injector working into a high-pressure boiler, or even the working of an ordinary injector, was somewhat paradoxical, and the action was still less easy to explain in connection with the complications of Mr. Sellers' self-adjusting injector and Mr. Gresham's self-acting pet-cock. There appeared to be no loss except from radiation or possibly leakage; and while it appeared extraordinary that water should by such means be caused to enter the boiler, it was evident that it did enter.

The exhaust injector, though very ingenious, had in his opinion one great defect in not being available at all for the chief use for which it was wanted, namely for feeding locomotives, for which injectors were principally employed. If the exhaust-steam injector were applied on a locomotive, it was found that another injector working with live steam was requisite to give the current a "kick-up" on its way to the boiler; and consequently in its application to locomotives the exhaust-steam injector became nothing more than a feed-water heater. He believed 70 lbs. was the very utmost boiler-pressure that this injector could force against; and to do so it required the feed-water to be very cold, as he had found from his own observation.

For attaining the same object as an exhaust-steam injector, but without using one at all, an apparatus of his own invention, which was simply an addition to the ordinary injector, had the advantage, while giving about the same economical results, that the ordinary injector with which it was connected worked quite independently of it; if there was any exhaust steam, the injector returned a considerable portion of it to the boiler; but if there did not happen to be any exhaust steam, the injector went on working just the same as if the apparatus were not there at all. In Fig. 9, Plate 23, A was the delivery pipe from an ordinary injector, B was the ordinary clack-box, and at C the delivery pipe had about 8 inches cut out of it, and the apparatus he referred to was inserted; its lower flange D was

connected with a branch pipe D E from the exhaust of the engine, and in connection with its lower branch was a back-pressure valve opening inwards. Fig. 10 was an enlarged sectional view of the apparatus, and its action was obvious; F was a contracted nozzle, like the end of the combining cone in an ordinary injector; G was similar to the receiving throat in an ordinary injector; and the interval between F and G represented generally the overflow portion of an ordinary injector; also G K was the ordinary delivery cone for gradually converting velocity into pressure. As the current rushed from F to G, the exhaust steam entering through the back-pressure valve H was condensed; and while the lateral or inductive action of the jet carried it onwards into the boiler, the temperature of the jet itself was simultaneously raised. The secret of the whole action lay not only in the proportion which the areas F and G bore to each other and to the throat of the injector, but also in the fact that an injector would force against a considerably higher pressure than the steam which worked it, so that a sufficient excess of pressure would be got at F for overcoming and penetrating the boiler-pressure at G. The back-pressure valve H prevented any water from escaping into the exhaust while the injector was being started. As the natural temperature of feed-water in England was about 56° F., or say 60° F. to be on the safe side for summer weather, and as the water was generally raised in every-day working 60° F. in its passage through the injector, it followed that there was $212° - 120° = 92°$ which might be added to the temperature of the feed by this apparatus; or as the last 12° was rather difficult to attain, say $200° - 120° = 80°$, representing an absolute gain of 80° F. on all the water evaporated in the boiler. The above was a practical calculation, and gave a result easy of attainment; and a practical way of testing the efficacy of this apparatus was to put one hand on the water-pipe leading to it, and the other hand on the delivery-pipe leading from it, when the difference would be found to be very striking.

Another method of his for dealing with exhaust steam was represented in Fig. 11, Plate 23, and was for returning exhaust steam into a boiler at any pressure, high or low, and without the aid of any live steam under any circumstances whatever. As

however in its present form it required plenty of cooling water, it could be used only for marine or land engines, and not always for the latter. A was a water nozzle, through which water rushed with nearly the velocity due to the pressure in the boiler, the effluent water having been led from a closed vessel, connected by a pipe with the water space of the boiler, through a long series of cooling coils or pipes, while the cooling water of course flowed in the reverse direction. The water jet then projected itself through the steam nozzles B, C, and D, against the throat E, where it encountered its own original pressure; naturally it could not enter here unaided, but in its course it had been assisted or had had a series of "kicks up" given to it by the exhaust steam entering at G, and so was enabled to penetrate the resistance at E, and through the usual diverging nozzle F to re-enter the closed vessel intermediate between the jet apparatus and the boiler. The exhaust steam assisted it in the following way:—the steam in the immediate neighbourhood of the jet was condensed; to fill up the local vacuum, more steam at once rushed in at a high velocity, and being directed by the shape of the nozzles B, C, and D into almost the same direction as the jet itself, it thereby accelerated the jet to such an extent as to enable it to penetrate at E. The action in this instrument resembled to a certain extent what took place in an ordinary injector, namely condensation, acceleration, and concentration; but it differed in this way, that the water, instead of having to be started from a state of rest, had already a certain momentum in it, and therefore required but little acceleration from the exhaust steam; and also the water jet was in the centre, instead of being an annular jet as in most injectors. The apparatus might almost be described as a combination of a surface condenser and a Morton's ejector condenser, with the advantages of both and the disadvantages of neither. No air-pump was required; and the same water being used over and over again, no scale was deposited except what fell from the small quantity of fresh water that was introduced. The action was continuous, water continually flowing at boiler pressure from the closed vessel in connection with the boiler, becoming cooled, passing through the instrument, taking up as much exhaust steam on its way

as it could condense, becoming accelerated in doing so, and then re-entering at a high temperature the closed vessel with the exhaust steam it had taken up, to go through the same process again as long as the engine was at work. The object of the closed vessel intermediate between the jet apparatus and the boiler was to economise the heat that was represented by the difference between the temperature of the heated water delivered from the jet apparatus and the boiler temperature; which difference, at 60 lbs. boiler pressure, was about 100° F. All that actually re-entered the boiler was an amount of water equal in weight to the condensed exhaust steam; and all the rest of the water returned direct to the jet apparatus through the cooler, without having been heated up to boiler temperature.

In the exhaust-steam injector described in the paper the leading and only new feature was the split nozzle with the hinged flap; and he asked what would be the effect of any solid substance getting under the hinge. It was all very well to say that if the injector stopped it would at once set about starting again; but if anything hard out of the feed-water did get under the hinge, the instrument would do nothing but stop and try to start again, and instead of doing any work would merely keep on "dithering." Nevertheless it was ingenious, though the principle of the idea was by no means new; for he had himself tested and worked, about fourteen years ago, an injector invented by Mr. Körting of Vienna, in which the combining cone was made in two parts, but divided transversely at such a point that the area where it was separated was greater than the area of the steam nozzle. When the injector had got up its penetrating velocity, the extra or first overflow was shut off from the air by turning a stop-cock, and the injector was at work; but of course, though it answered the same purpose, it was not automatic; in this point only was it inferior, for it had all the other advantages of the injector described in the paper. If however it were decided to have an automatic injector, let it be a substantial one, in which there was more power to overcome obstacles; for this purpose its closing action should be dependent on the powerful boiler-pressure, and not on a comparatively weak, uncertain, and only partial vacuum. Such an

instrument was shown in Fig. 12, Plate 23. It looked like an ordinary injector, but internally it had two overflow spaces—the ordinary one at A, and an extra and temporary one at B. The temporary one was for the purpose of starting the injector, and its area was somewhat greater than that of the steam nozzle C. Its action was as follows:—the steam issuing at C rushed through B and A, forming a vacuum in the water space, into which up rushed the water; and the water being driven forwards by the steam and creating a pressure at D, the combining nozzle D A B was then forced up, the overflow at B was firmly closed, and the injector was at work. Here the moveable combining nozzle resembled to a certain extent the moveable nozzles in the injectors of Mr. Sellers and of Messrs. Robinson and Gresham, but was of course for a totally different purpose. This injector would work with either live or exhaust steam or both together; it could be placed either above or below the feed-water, and was perfectly automatic; it had however to be placed vertically, so that the combining nozzle D A B should fall whenever the action stopped, and so be ready to start again. The particular injector shown in Fig. 12 was arranged to be worked by live steam from a high-pressure boiler, and to be placed either above or below the level of the feed-water. For working with exhaust, the steam and water nozzles would require to be differently proportioned; and except as regarded the starting, there was really no difference whatever between an exhaust and a live-steam injector, beyond the relative sizes of the working parts.

It might be mentioned that, up to the time of the invention of the exhaust-steam injector, the most that had been done in that direction had consisted—either in introducing exhaust steam into the overflow of the ordinary injector: which was bad, because the overflow should always be free, and indeed most drivers liked to be able to hear it;—or in having a central exhaust nozzle inside the jet of live steam: which was also bad, because when air got in with the exhaust it was of course not condensed with the steam in the combining cone, but merely compressed into globules, which burst the jet at the overflow space and stopped the injector. In addition those injectors were difficult to start, and when started were liable to

stop; and when stopped they required an attendant to start them again. Hence the demand for automatic exhaust-steam injectors.

Mr. W. Steele Tomkins, having had to do with the manufacture of the exhaust-steam injector when it was first brought out, said it was very interesting as an entirely new application of the principle of the injector; it was also clearly a source of great economy, opening a very wide field for saving. He had been very much struck when he first saw it working on a locomotive against 120 lbs. pressure, with exhaust steam only; but it must be confessed that in that particular engine the back pressure was greater than usual. It was not stated in the paper, but it might be taken to be the fact, which no doubt the author would clearly confirm, that the back pressure in the cylinders when exhaust injectors were working was of course reduced. With regard to the economy, he would not anticipate what the author would have to say, except by remarking that as compared with any feed-water heater there was this difference: that the feed-water heater *might* be doing its best at all times, but the injector *must* be doing its best at all times. There was no question that the economy which it professed to give was obtained. What that would be, he would leave the author to explain. On locomotives as well as on stationary engines the exhaust-steam injectors were already working in some considerable numbers. It was quite true that the application was not so simple as in the case of the live-steam injector; but for all that, the economy obtained was perfectly uninterfered with. With regard to the injector with the sliding nozzle divided transversely, which had been described by Mr. Sharp, the same idea had occurred to himself in Manchester some time ago; but he thought it ought to be said that the results hitherto had not been quite so good as had been anticipated, and at all events were not yet worth mentioning.

Mr. Charles Cochrane was sure that, if there was any difficulty in explaining how steam at high pressure could feed its own boiler, the difficulty was intensified when it came to exhaust steam doing the same. He had applied the exhaust-steam injector at the Woodside

Iron Works, Dudley; and had entered upon the experiment with great misgiving as to its success, though he was comforted by the thought that others had been before him, and that there need be no risk. He had been astonished to see the way in which exhaust steam from an engine would, while relieving the engine during the time of feeding the boiler, supply the boiler itself. But while the exhaust-steam injector, when applied where there was only cold water available for feeding the boilers, was invaluable for warming the cold water up to the highest point possible during the time of feeding, he would call attention to the fact that this warming took place during only a few minutes. The injector was so rapid in its action that the boiler was fed up full in a few minutes, less or more; and during the whole of the rest of the time the exhaust steam was escaping from the engine without doing any work whatever. The benefit of the exhaust-steam injector was great in the way of delivering hot water into the boiler, but the economy he thought was not much, because of the shortness of the time during which the feeding was taking place; the short time so occupied was trifling compared with the length of time during which the exhaust steam was escaping unused into the atmosphere.

Mr. PETER D. BENNETT said he had three or four of the automatic exhaust-steam injectors at work at the Horseley Iron Works, Tipton. The difficulty started by Mr. Cochrane was got over by putting in an ordinary throttle-valve between the exhaust-steam pipe and the injector, and by opening the valve only far enough to admit as much exhaust steam as would just keep the feed-water continuously going into the boiler. By that means the cold feed-water was regularly heated up to probably between 160° and 170°. He regarded the exhaust-steam injector as one of the most ingenious contrivances he had ever met with; and the three or four he had at work were acting in the most perfect manner. They had simply been put on the boilers, and the connection made to the vertical exhaust-pipe by means of a horizontal pipe with an ordinary throttle-valve inserted for regulating the admission of the exhaust steam; and the injector then went on working in the most perfectly automatic way conceivable.

The invention he considered was one that ought to be generally known; and if known he believed it would be generally used.

Mr. JAMES GRESHAM said that, Mr. Sharp having anticipated most of what he had been about to say, he would only add that he looked upon the invention of the exhaust-steam injector as one of the greatest steps in the last quarter of a century. Having himself been connected with injectors for rather more than that length of time, he considered the only great improvement that had been made upon them was this of working with exhaust steam, which he believed dated back at least eleven years. The instrument represented in Fig. 12, Plate 23, with combining-nozzle divided transversely and sliding vertically, nearly illustrated an injector which he should have sketched himself if Mr. Sharp had not done so; and he believed it was one that would work as well as that with the flap nozzle, when designed as some had been that were still working; but it would not work with exhaust steam without a much larger steam-nozzle. He had much pleasure in testifying to what he considered the excellence of the injector described in the paper, and he thought that great credit was due to those who had first been bold enough to think that exhaust steam could be used at all. He was certainly anxious, as others had been, to hear some scientific explanation of the working of the exhaust-steam injector, both theoretically and practically, which did not seem to have been clearly set forth.

Mr. DRUITT HALPIN thought the easiest way of looking at the action of the injector, and at the seeming impossibility of an injector with steam of atmospheric pressure delivering water into boilers at a higher pressure, was to regard it purely as a thermodynamic question. It could be reasoned out by changes of velocity; but the easiest way was to look at it as a question of a certain amount of steam—either exhaust steam or steam of any pressure whatever—which was at a certain temperature, and contained a certain number of thermal units: that steam simply did a certain amount of work, in lifting water up to a certain level, and then forcing it into the boiler. Mr. Sharp had remarked that the only waste that took place

was by radiation. Radiation was no doubt one source of waste; but allowance should also be made for the heat converted into mechanical work in performing the work of feeding the boiler itself.

Mr. James G. Daw thought that, from what they had now heard with regard to the practical working of the exhaust-steam injector, every one must be deeply interested with the novelty of the invention. But what was now required was to consider its utility. It had been mentioned by Mr. Bennett that cold feed-water was heated by the injector up to between 160° and 170°. With an ordinary feed-water heater worked by the feed-ram he had raised cold water up to 212° before putting it into the boiler, measuring the temperature by a very thin copper plug, which was inserted into the feed-pipe and was connected with a sensitive thermometer outside. Mr. Cochrane had spoken of the injector being very rapid in its action; and probably that would give some difficulty to the engine-man. He should be glad to hear something more concerning the actual advantage of the exhaust-steam injector as applied to boilers; if there was no clear advantage, he should be somewhat cautious before introducing it for feeding boilers.

Mr. James Platt said his firm had one of the exhaust-steam injectors, and had perhaps used it under very unfavourable circumstances. The boiler was at a distance of some 60 feet from the engine; the exhaust steam passed through six bends, and there was no throttle-valve in the exhaust pipe; there was simply a connection from the exhaust pipe to the injector at the bottom of the first bend nearest the cylinder. The injector worked exceedingly well, being of the proper size for the boiler, so that it was continuously at work, with the consequent advantage of saving the maximum heat out of the exhaust steam during the whole time; it answered all the purposes for which it was intended. But a difficulty had been found from the water containing a considerable quantity of carbonate of lime and some other substances, and from part of the grease from the cylinder being carried into the boiler, which had occasioned a good deal of trouble, producing a bulging of the

furnace plates. With the exception of that difficulty the injector had answered all their expectations; and it was really an admirable invention.

Mr. WILLIAM ANDERSON pointed out that the theory of the action of the injector had been explained, a considerable number of years ago, both by the late Sir William Siemens and also by Sir Frederick Bramwell, in connection with papers* read before this Institution by Mr. Robinson and before the Institution of Civil Engineers by Mr. England. The explanations they had given were remarkable for their simplicity and lucidity, showing how it was that the injector, acting with steam at a lower pressure, would even put water into a boiler at a higher pressure. In the use of exhaust steam for feeding a boiler at 75 lbs., the difference of pressure might be rather greater than that alluded to in those explanations; but the principle was the same.

Mr. WILLIAM SCHÖNHEYDER agreed with previous speakers that, in addition to the saving of heat by the use of the exhaust-steam injector, there was also a saving of feed-water. Of course there was a considerable proportion of feed-water put into the boiler in the shape of exhaust steam, he thought about 15 per cent.; so that, where feed-water was scarce, this was an advantage; and it was clean water.

Mr. JAMES B. ALLIOTT said that some little time ago his firm had had experiments conducted with reference to the exhaust-steam injector, with the special object of testing the exact increase in the temperature of the feed-water, and also the increase in the quantity of it from the addition of the condensed steam. In regard to both points the results varied very much with the quantity of water that was being fed through the injector. With a small feed the

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* Proceedings Institution of Mechanical Engineers, 1860, pp. 48–50, and 78; 1861, p. 227; and 1866, p. 274.

Proceeedings Institution of Civil Engineers, 1865, vol. xxiv., pp. 222, 228, 236.

temperature of the water was much more increased than with a large feed. Of course as the temperature was increased, so also the proportion increased of condensed steam which mixed with the feed. With a large feed there was an increase in quantity of between 14 and 15 per cent., and an increase in temperature of between 76° and 78°. With a small feed there was an increase in quantity of 21 per cent. and in temperature of 122° or 123°. Obviously in some instances the increase in the quantity of feed-water would be a matter of some importance; but in all cases the increase in temperature was of course a matter of very considerable economy. An injector which made use of exhaust steam alone, for the purpose of feeding a boiler, he thought was not capable of application to all boilers or under all circumstances; but the number of instances in which such an injector was applicable was very large, and wherever it could be applied its advantages were obvious.

The hinged flap which formed a portion of the split nozzle in the automatic injector had been spoken of as a part that might be expected to be troublesome and delicate in its action. At his own works boilers had been fed with one of the injectors for the last two years and eight months; and by way of testimony from actual experience the nozzle and flap of that injector were now exhibited, and he thought it would be found on examination that they had not suffered from their working during that period. He was not aware of any instance in which any foreign matter had found its way into the flap and stopped the action of the injector; yet he could not say that his feed-water was of a very fine quality or that it was free from impurity.

Mr. Savill, replying to the comment which had been made on the need of live steam for feeding boilers at higher pressures than 75 lbs., said the paper had not dealt with the application of the exhaust-steam injector to locomotives, as that subject was of sufficient importance to be dealt with in a separate paper. The exhaust injector heated the feed-water up to 190° and gave it a pressure of 75 lbs.; then it wanted a fillip to carry it into a locomotive boiler at 150 lbs. pressure. This additional impulse was given by a separate smaller

or supplementary injector, worked by the boiler steam, and so proportioned as to take feed-water of 190° or any higher temperature, and force it into the boiler. The steam taken from the boiler to work this supplementary injector of course heated the water additionally, and was returned into the boiler. Supposing the exhaust steam alone had been sufficient to enable the water to penetrate into a boiler of 150 lbs. pressure, the water so forced in would have a temperature of say 190°; and when it got into the boiler it would have to mingle at once with water of over 360°. But if by using steam from the boiler the feed-water could be heated up to say over 280°, there could be nothing lost, because whatever steam was taken from the boiler for working the supplementary injector was returned into the boiler again in the feed-water, while at the same time the water would be heated nearer the temperature of the water in the boiler, which would be admitted to be an advantage and not a disadvantage.

Of the contrivances described by Mr. Sharp, some had been experimented with at the Atlas Works, Manchester, several years ago, and as mentioned by Mr. Tomkins they had not been found to be practically of much value. It was true they had worked with exhaust steam and fed a boiler up to 70 lbs. pressure; but then they took so long to start, and they were so delicate in starting, not being automatic, that practically they would be no good for ordinary use. What was wanted was something quite automatic, that did not require starting at all, but would start of itself; and the flap of the split nozzle did that undoubtedly, as known from actual experience. He had himself tested nozzles similar to those shown in Figs. 11 and 12, Plate 23; but they had been practically no good, for the reasons above stated.

With regard to Mr. Sharp's scheme for using an ordinary injector and then heating the feed-water by means of exhaust steam after it had left the ordinary injector, that was beginning at the wrong end; what was wanted was to heat the feed-water with exhaust steam when it was cold, so as to get the full benefit of the exhaust steam; and then the heating could be carried on higher with the boiler steam afterwards. Taking the natural temperature of the feed-water as 60°, Mr.

Sharp had added 60° as the heating which would occur in an ordinary injector supplied with steam enough to give the requisite power for forcing the water into the boiler. For locomotives perhaps the 120° so arrived at was a little under-estimated; in fact in an injector supplied with steam at 60 lbs. pressure it would be found that about 160° was the temperature to which the feed-water was raised. But taking it at the low figure of 120°, it had been stated that the feed-water could then be heated up by exhaust steam afterwards to 200° as a minimum. That was an addition of only 80° due to the exhaust steam; but with the exhaust injector, taking in water at 60° and heating it up to 190°, the addition amounted to 130°. In the case of a locomotive running at a quick speed it was found that the temperature went up not only to 190° but even to 208°, with the exhaust injector alone; in that case, owing to the high speed, the injector had had good hot dry steam to do the work. As to the exhaust injector not being available for locomotives, he was glad to say that a large number were working on locomotives, and giving every satisfaction. In fact the above figures were from actual locomotive practice, and showed a very marked difference from the arrangement described by Mr. Sharp; the latter was estimated to deliver water into a locomotive boiler at 200° when using both boiler and exhaust steam, whilst the exhaust injector delivered it at over 270° under the same conditions.

The injector brought out some years ago by Mr. Körting was admitted by Mr. Sharp to have been practically a failure; and therefore no more need be said about it now.

The injector working on the principle of a piston, sketched in Fig. 12, Plate 23, was very similar to the self-adjusting injector of Mr. Sellers, which had been thought at one time to be a great improvement; but in actual practice it had been found not to work well, as the piston was liable to stick; and very few of those injectors were at work in England at the present time. If one of them were tried with such water as was used by Mr. Alliott at Nottingham, he was persuaded it would fur up.

The economy of the exhaust-steam injector was certainly one of the most important points in connection with its use. When, as

was often the case, a live-steam injector had been used prior to the introduction of the exhaust-steam injector, both of them taking their feed-water at its natural temperature, an advantage was found in economy of fuel, with stationary engines, of never less than 20 per cent. and often of more, in favour of the exhaust injector. In feed-water heaters, the percentage of economy varied considerably; and a feed-water heater was a very good thing as long as it was big enough, but a very large heater was required to do a small amount of work.

Mr. COCHRANE understood the statement that the economy in fuel with the exhaust-steam injector was 20 per cent. greater than the economy with an injector worked by high-pressure steam; but he should be glad to know what was the absolute saving by the former, because it had been spoken of as about 15 per cent., that being according to Mr. Schönheyder the proportion of feed-water returned into the boiler in the shape of exhaust steam.

Mr. SAVILL could not give the absolute saving by the exhaust-steam injector, because he did not know the actual economy shown by an ordinary live-steam injector over a pump; but he thought this could not be very great in respect of fuel. No doubt there was a great economy in an ordinary injector over pumps; but it was not so much in fuel, because the loss in the pump was only from friction; the chief economy of the injector over the pump was in respect of wear and tear. The exhaust injector, showing an economy of 20 per cent. over a live-steam injector in the fuel alone, showed 25 per cent. economy he believed over a pump pumping cold water into the boiler.

Mr. COCHRANE asked whether the question might not be answered if put in this way: how much of the exhaust steam was got back into the boiler?

Mr. SAVILL replied that of course that would depend upon whether the boiler was merely supplying steam for the engine, and

for nothing else; in which case from one-fifth to one-sixth of the exhaust steam was taken back into the boiler by the injector.

Mr. Cochrane thought that proportion would about correspond with the increase which had been mentioned of the feed-water temperature from 50° to 190°, an increase of 140°.

Mr. Savill believed those figures would be found to be not far wrong as a fair average; isolated cases could be picked out that were a great deal better, and others that were worse. The economy in the quantity of feed-water used might be taken roughly at about 15 per cent.; it was difficult to tell exactly what it was, because in very few boilers was the water measured. Some elaborate experiments had been made last October at Nottingham* by Messrs. Manlove Alliott Fryer & Co., which showed 15 per cent. saving in quantity of feed-water, and an increase of $1\frac{1}{2}$ lb. of water evaporated per lb. of coal, in favour of the exhaust-steam injector over a feed-pump.

The President observed that the increase in the temperature of the feed-water would give the exact quantity.

Mr. Cochrane said that was what he had been looking at, and his own calculations on that basis led him to agree with the author that one-seventh was about the quantity of feed-water that could be saved.

Mr. Savill explained that the reason of the injector at Mr. Cochrane's works filling up the boiler at once, and then having to stop for an hour, was simply that the size of the injector was too large for the boiler. He always objected to putting on an injector too large for the boiler, because it was better to keep the injector constantly going; it should be just a little larger than required for the maximum work, but not too large.

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* See *Engineering*, 18th April, 1884, pp. 339–340.

Another respect in which the exhaust-steam injector differed from an ordinary live-steam injector was that when it was working it acted beneficially on the engine piston, especially if there was a little back pressure, as it had the effect of diminishing the back pressure of the exhaust steam.

Respecting the wear and tear of the hinged nozzle, he exhibited the nozzles of three injectors, and also one complete injector, in order to show what effect constant use had had on them. All had been working for over two years, and it would be seen that they were practically as good as when new, nothing whatever having been done to them except wiping them with a sponge cloth, so as to show the surfaces up. The first nozzle was from a No. 8 injector of the locomotive type, which had been working in Manchester. The second was the nozzle of a No. 7 injector, kindly brought by Mr. Alliott, which as stated by him had been working with Nottingham water for two years and eight months; and it would be admitted that it was but little the worse for so doing, although the water was none of the best, but rather the reverse. The third nozzle had been taken that very evening from a No. 4 injector working with London water, and had not even been cleaned for over six months. The complete injector was a No. 4, which had been working in Manchester for more than $2\frac{1}{2}$ years. The excellent condition of all these hinged nozzles was a proof both of their durability, and also that the fear lest something hard might happen to get under the hinge was not realised in practice, otherwise the metal would show marks of the occurrence. It was indeed impossible for anything to get under the hinge, because anything that could pass the large opening at the hinge would be free to pass completely through the nozzle, while anything too large to pass through the opening could never reach the hinge.

The question of grease getting introduced into the boiler along with the exhaust steam was one that depended entirely upon the way in which the branch exhaust-pipe going to the injector was led off from the main exhaust pipe. If the branch was to be taken off from a vertical main pipe, the connection should be made at right angles, as shown in Fig. 4, Plate 21; and if from a horizontal main

pipe, then the branch must be taken from the *top* side of the pipe, because if it were led off from the bottom the grease would undoubtedly run into the branch pipe and be carried into the boiler; but when the branch was connected on the top of the horizontal exhaust-main, he had found that practically no grease at all was carried into the boiler. No trouble from grease had been experienced in any of the boilers on which the injectors now exhibited had been working, the branch-pipe connections being made in conformity with these recommendations. The trouble experienced by Mr. Platt had arisen from the fact of the branch exhaust-pipe having been in that case led off vertically downwards from the lower side of an elbow at the bottom of the main vertical exhaust-pipe; the branch pipe formed therefore a trap, into which the grease running down the sides of the vertical exhaust-main would collect; and the exhaust steam flowing to the injector would carry the grease along with it, and deliver it into the boiler. Had the branch to the injector been taken off higher up from the vertical exhaust main, there would have been no trouble from the grease. Notwithstanding the number of exhaust injectors now working, both in this country and abroad, under almost every conceivable condition, he had had up to the present time only one other complaint respecting grease, besides that now mentioned; and in both cases the trouble was traced to the wrong manner in which the branch exhaust-pipe was connected to the main exhaust-pipe.

The President was sure the Members would all agree with him in thanking the author of the paper for having brought before them what, until it had been seen, would be regarded as an almost incredible mode of feeding a boiler.

DESCRIPTION OF THE APPARATUS USED FOR TESTING CURRENT-METERS, AT THE ADMIRALTY WORKS AT TORQUAY FOR EXPERIMENTING ON MODELS OF SHIPS.

BY MR. ROBERT GORDON, OF BURMAH.

The Current-Meters to be tested are towed by a dynamometrical apparatus through still water in a large tank, which gives a parallel-sided water-space 278 ft. long, 36 ft. broad, and for the most part 10 ft. deep, though it shallows up at the ends. It is roofed from end to end, the framework of the roof carrying a light railway with a clear space between the rails, which run the entire length of the building at about 20 inches above the normal water-level. In Figs. 1, 2, and 3, Plate 24, is shown the general arrangement of tank and railway.

A stout-framed truck T, Fig. 4, Plate 25, suspended from the axles of two pairs of wheels, runs on the railway, and carries the recording and measuring apparatus. A sheet of paper is wound round a cylinder R, carried by the truck; and the cylinder is moved by a band from the hinder axle, so that the circumferential travel of the paper represents, on a reduced scale, the forward motion of the truck. A pen A, actuated by clockwork, marks time on the cylinder as it revolves. A second pen B is moved electrically, and marks indents on the recording paper for every 25 ft. run by the truck. A third pen C, moved electrically, can be used for recording the number of revolutions made by the meter under trial, contact being made inside the meter in the method actually arranged for use. A fourth pen D is required for recording the force actually used for towing the object through the water. Generally not more than three or four pens are used at one time for recording: another occasional pen E is sometimes required to show slight quick or slow variations in the rate of speed of the truck and object during the experiment. The

arrangement of all five pens is shown in Fig. 4, Plate 25, together with the recording cylinder R, and the resistance-measurer or dynamometer G. A sixth pen F is used in ship-model experiments, as well as the pen C, so as to record the indications of two very small and delicate current-meters, which precede the model some distance ahead, and show whether the speed of the model through the water differs from the measured speed over the ground, in virtue of any slight current set up by previous experiments. Specimens of the actual records taken are shown full size in Figs. 8 and 9, Plate 27; Fig. 8 shows records from the pens A, B, F, and C; and Fig. 9 from the dynamometrical pen D.

The dynamometer consists of a vertical beam G, Fig. 4, hung on a fixed centre H by a double knife-edge suspension. From its lower end a link L takes the towing strain of the model; while a knife-edge fixed in the beam G, at an equidistant point above the centre H, carries one end of the spring S, whose extension measures the resistance of the model, the other end being attached to a knife-edge N, fixed in the truck. The uppermost extremity of the beam is linked at J to the multiplying lever M, which moves the resistance-recording pen D on the paper. An extensive collection of springs permits by substitution any resistance to be measured; but the actual strain corresponding with the indications of the recording pen is determined by weights W applied to the end of the horizontal lever K at a point whose distance from the centre H equals that of the towing link L and the resistance-spring S.

The arrangement for testing the Deacon meter is shown in Fig. 4, Plate 25, where a round bar nearly an inch in diameter carried the meter; but it was found expedient in the rating experiments to substitute for the round bar one of tapering or fish-section, as shown at P in Fig. 4 and to a larger scale in Fig. 5, Plate 26, set with its edges in the direction of the run, as the round bar was observed to cause eddies and a disturbance in the water, likely to interfere with accuracy of record in the instrument when used for high velocities. Some very valuable experiments had previously been made at these Works, bearing on this point, when bodies of globular and other shapes had been towed at various speeds while loosely

held by a cord. It was found that the globes wobbled and danced about violently, owing to the eddies formed behind them; but by lengthening out the *rear* end of each globe to a point, great steadiness ensued, and the objects followed in straight lines. It is proposed to utilise these results in future meters.

The truck is moved by an endless wire-rope coiled in a spiral groove on an accurately turned barrel, which is driven by a small double-cylinder engine, having a heavy and highly-speeded fly-wheel, and a governor of very exact action, of such arrangement that any required steady speed from 40 up to 1000 ft. per minute can be assigned by it to the truck.

The governor is complicated with a number of parts formerly useful, but now no longer required; in principle it may be described in general terms as a modification of the Watt governor, but greatly improved. In the ordinary governor the action is due to the position of the balls, which in virtue of their altitude, rising with increase of speed, shut off the steam at the throttle-valve: the reverse happening when they fall lower. In Mr. Froude's governor, illustrated in the diagrams, Figs. 6 and 7, Plate 26, the balls are not allowed to travel outwards beyond a certain angle; beyond this angle the link L, acting on the inner end of the stationary lever V, against the fulcrum F, presses a brake-block B against a disc D, which rotates about the same spindle and with the same angular velocity as the governor balls; so that whenever a proper amount of steam is used, and when there is no variation in load, the balls will revolve at their proper angular altitude, and the stationary brake-block will be just in contact with the rotating disc, but exerting no pressure upon it. But should an excess of speed take place, however small in amount, due either to lessened load or to increased steam-pressure, then immediately pressure will exist between block and disc, proportioned to the excess of speed, which pressure will tend towards making the block accompany the disc in its rotation; but this motion is hindered and kept within narrow limits by the pull of a spring S, which keeps the block against a fixed stop so long as the true speed is maintained. The travel of the block away from its stop is a measure of the

friction between the brake and the disc, or in other words is a measure of the excess of speed.

The position of the brake-block governs the extent of opening of the throttle-valve, which is open when the block is close home to its stop, and becomes closed as the block departs from the stop, that is as the excess in speed over that required becomes larger. The steam pressure is thus cut off immediately there is any excess of speed. The adjustment of the critical speed at which the throttle-valve becomes acted upon is made by adjusting the position of the governor balls W along the arms A. Also the centripetal force is given, not by the statical weight of the balls as in the Watt governor, but by springs C, the arms and balls being statically balanced.

This arrangement acts with such accuracy and delicacy that a variation in speed of half a foot per minute is rarely found to occur, even in the fastest runs of the truck. In practice such variations are observed with sufficient accuracy on the "speedle," which is a water column in an open glass-tube fixed near the hauling engine. The head of water in this tube is maintained by a centrifugal pump worked through suitable gearing by the rotating shaft of the engine. A scale placed alongside the tube shows the speed at which the truck is moving at the time when the observations are made. The scale was marked by actual experiment and by subdivision; a height of 3½ inches of water column measures a variation in speed of 10 ft. per minute when running at about 300 ft. per minute.

In testing either ship-models or meters, a length of only 150 to 200 ft. in the central part of the run of the truck is used, a certain portion being allowed for getting up and lowering down speed at the ends. For certain purposes it has been found desirable to have a longer run; and arrangements are in progress for moving the whole establishment to Haslar, where the new tank will be something like 500 ft. long.

In rating the Deacon meters it was not found necessary to have a great number of experiments, each at a different speed; but usually only three speeds were employed, of 1 ft., 2 ft., and 8 ft. per second;

and a master curve gave all the intermediate speeds. This standard or master curve is one obtained from a series of experiments with meter No. 1, and may be looked upon as perfectly accurate in giving the rate-curve of this meter at the time of trial.

In Fig. 10, Plate 27, are given the rate-curves of this meter and of two others, in order to show the method of inferring the rate-curves of the different meters from the master curve shown by the strong line. The abscissæ represent the speed in feet per second, the ordinates the travel of the log through the water for a given number of turns of the screw. The curves are *similar* curves, those of meters Nos. 10 and 11, shown by the dotted and full fine lines, being inferred by a process of trial and error from the master curve of No. 1 by appropriate alterations in the scales for the ordinates and abscissæ. The reasons for this similarity are founded on mathematical considerations not immediately obvious, but which need not be entered upon here.

Any small current in the water of the tank, such as may arise from draughts of air or from the previous experiments, proves quite sufficient to produce very tangible error in the indications of individual experiments. For eliminating such errors in testing the meters, the plan was at first tried of reversing the meters at the end of each run, and making an experiment in the opposite direction after a sufficient interval of time. But it was found that this method, whilst eliminating the error from fortuitous variation of current, due to draughts or other accidental causes, introduced a fresh error from the fact that there was always a current against the direction of the run, caused by the water disturbance and by the wind of the truck in the previous run. To avoid this, the practice now is, after each experiment in one direction (say from north to south), to return instantly (from south to north) at the same speed, in order thereby to obliterate as far as possible the effect on the current; then lift the meter out of the water, and travel *slowly* back from north to south; and then replace the meter to face northwards, and take a new experiment from south to north. The mean of such a pair of experiments, or still better of two pairs, will be very free from error due to current.

The foregoing account has been prepared with the kind permission and aid of Mr. R. Edmund Froude, of the Admiralty Experiment Works, Torquay; and with the help of Mr. J. R. Perrett, who supplied explanations and drawings.

Discussion.

Mr. Gordon wished to call particular attention to the beautiful governor described in the paper, the action of which was exquisite. It had been designed and modified by the late Mr. Froude, and it was perfectly marvellous to see the accuracy and ease with which any speed from 40 up to 1000 ft. a minute could be given by it to the truck. He was surprised that it had not been used in ordinary practice. It was very easily constructed. There was a right-and-left-hand screw by which the balls were moved along their arms, outwards or inwards. There were three pulleys on the engine-shaft, and a strap from one or other of these three pulleys gave three rates of speed. The adjustment of the governor balls on their arms gave the means of altering the speed of the truck from 200 to 330 feet per minute; and the rest of the range of speed was got by shifting the strap on the pulleys.

The President presented the thanks of the meeting to Mr. Gordon for the very interesting paper which he had brought before them.

PORTABLE RAILWAYS.

Plate 4.

Dished Sleeper.

Fig. 1. *Elevation.*

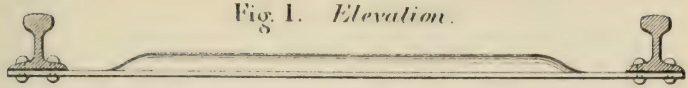
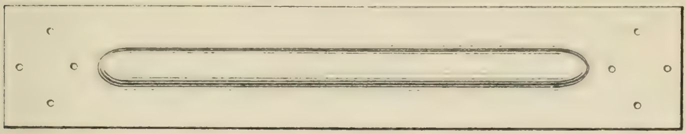


Fig. 2. *Plan.*



Bowl Sleeper.

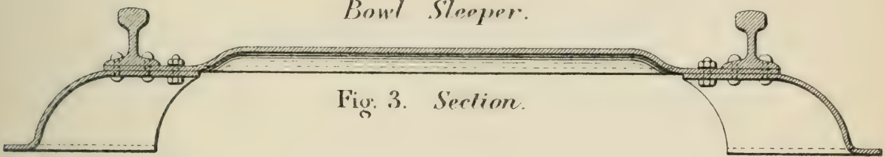


Fig. 3. *Section.*

Scale 1/8th

Fig. 4. *Plan.*

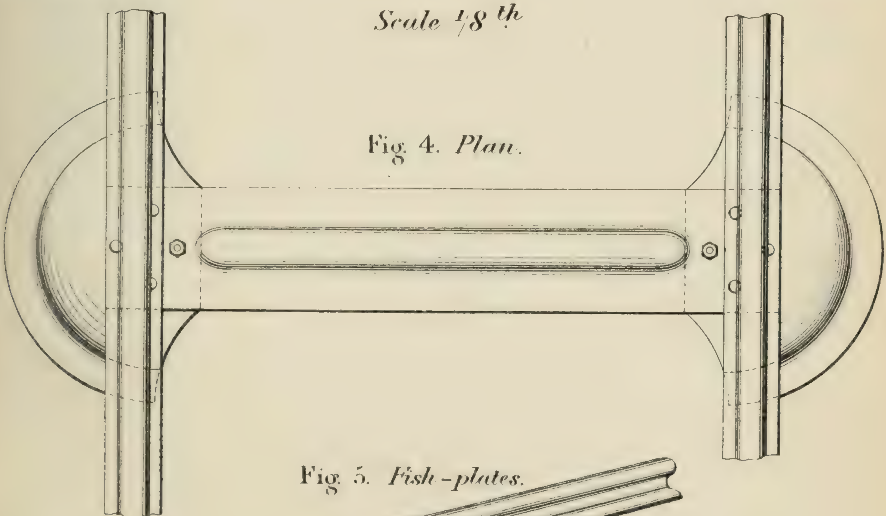


Fig. 5. *Fish-plates.*

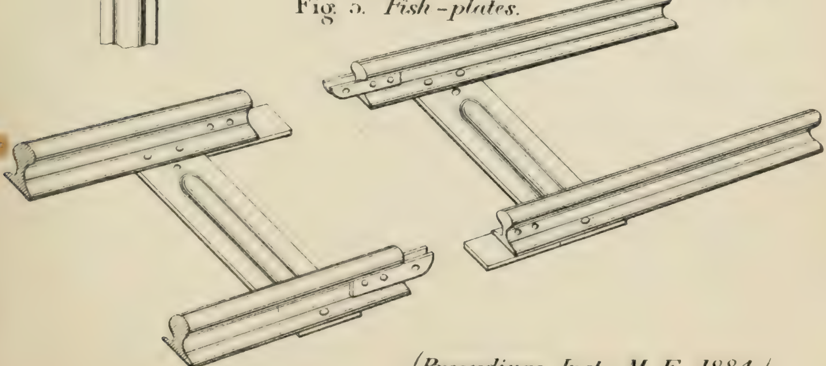
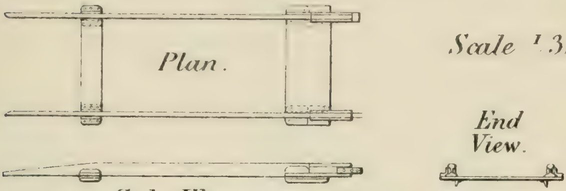
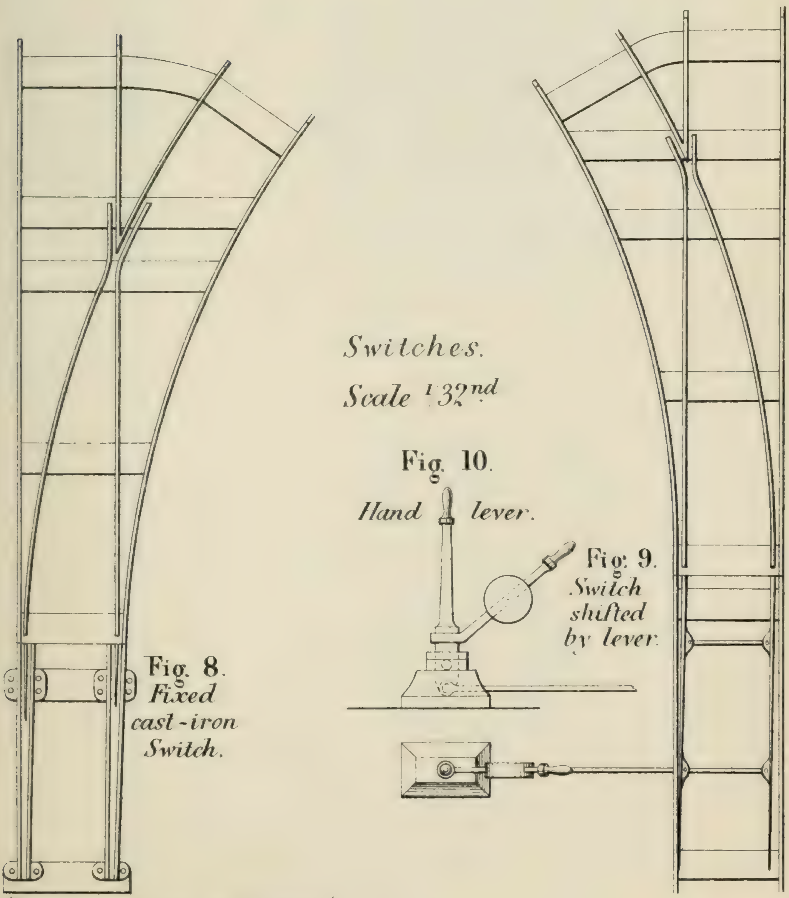


Fig. 6. *Curve. Scale 1/32nd*

Fig. 7. *Off-railer.*



Scale 1/32nd



PORTABLE RAILWAYS.

Fig. 11. *Smooth Turntable.*

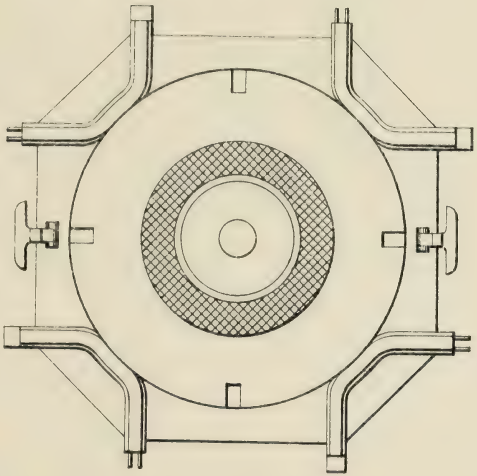
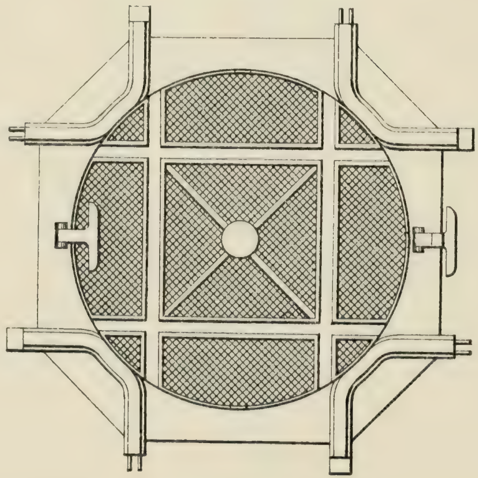


Fig. 12. *Grooved Turntable.*



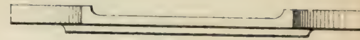
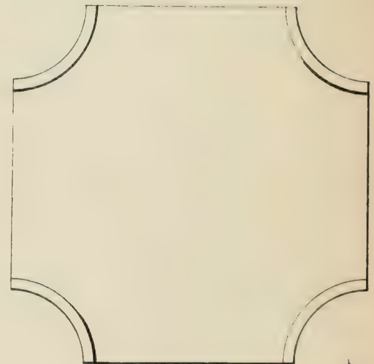


Fig. 13. *Dead Plate.*



(Proceedings Inst. M. E. 1884.)

Scale 1/16th.

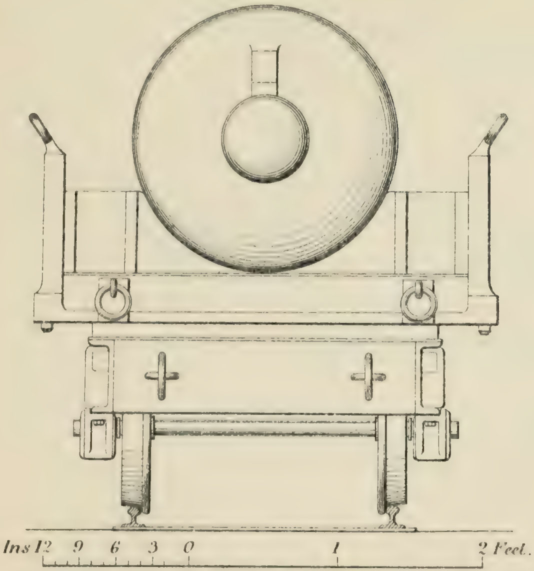
Ins. 12 6 0 1 2 3 Feet.

Plate 6.

PORTABLE RAILWAYS.

Truck for Cannon, Timber, &c.

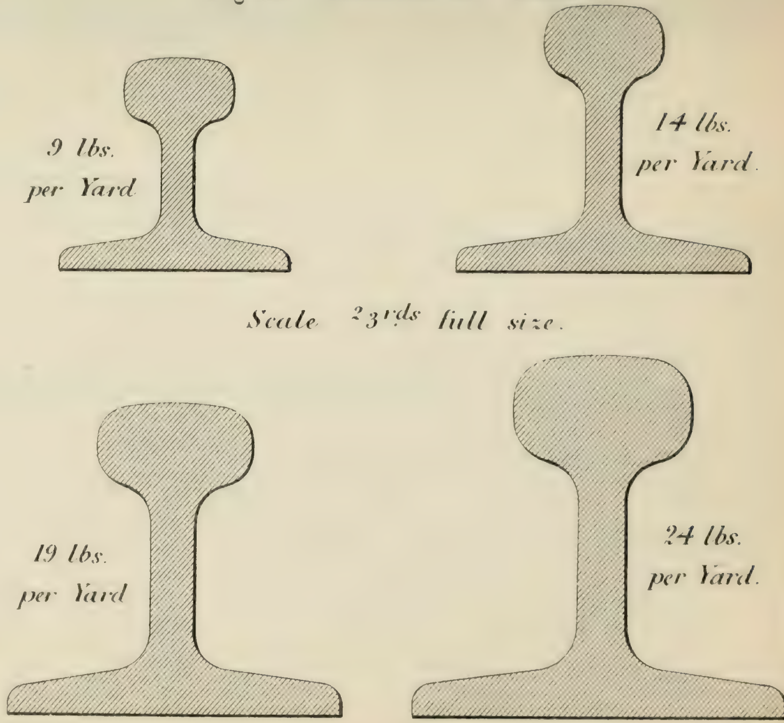
Fig. 15. End Elevation.



(Proceedings Inst. M. E. 1884.)

Scale 1/16th

Fig. 14. Sections of Rails.



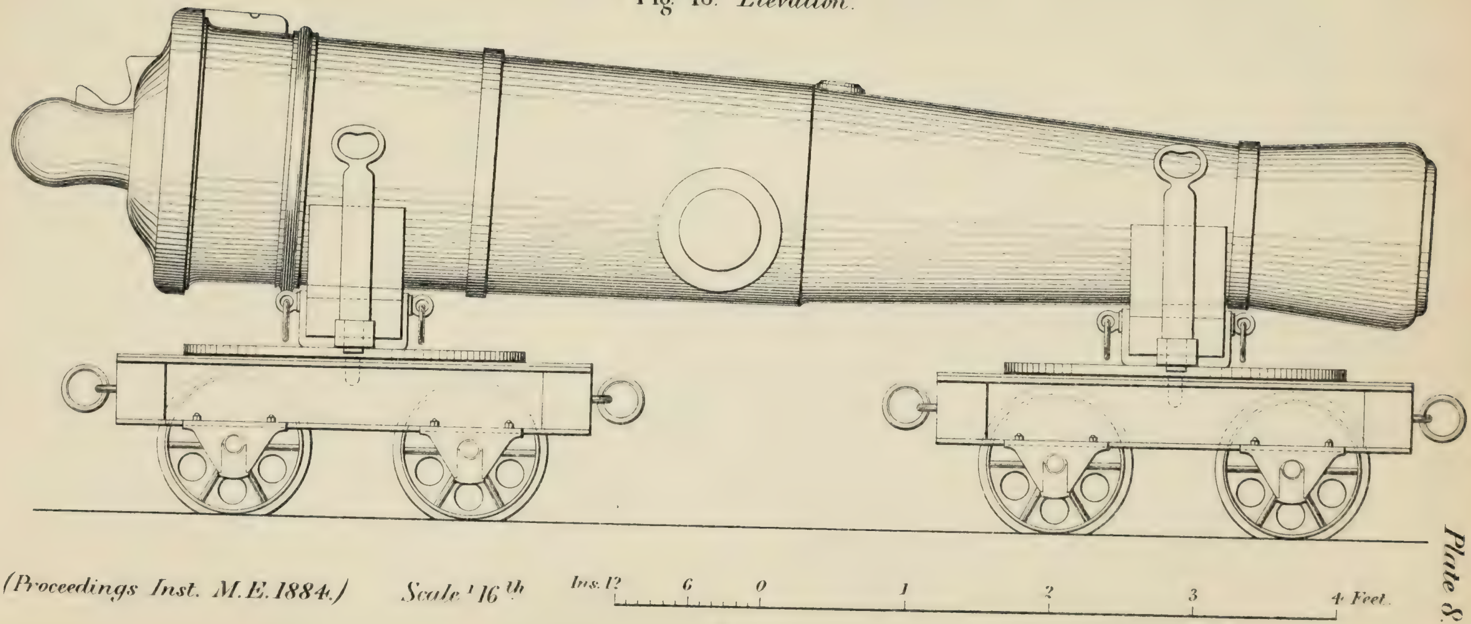
Scale 2/3rds full size.

Plate 7.

PORTABLE RAILWAYS.

Trucks for carrying Cannon, Timber, &c.

Fig. 16. *Elevation.*



Scale 1/16th

Plate 8.

PORTABLE RAILWAYS.

Plate 9.

Wagon with Tipping-box, for heavy earthwork.

Scale 1/15th.

Fig. 17. *End Elevation.*

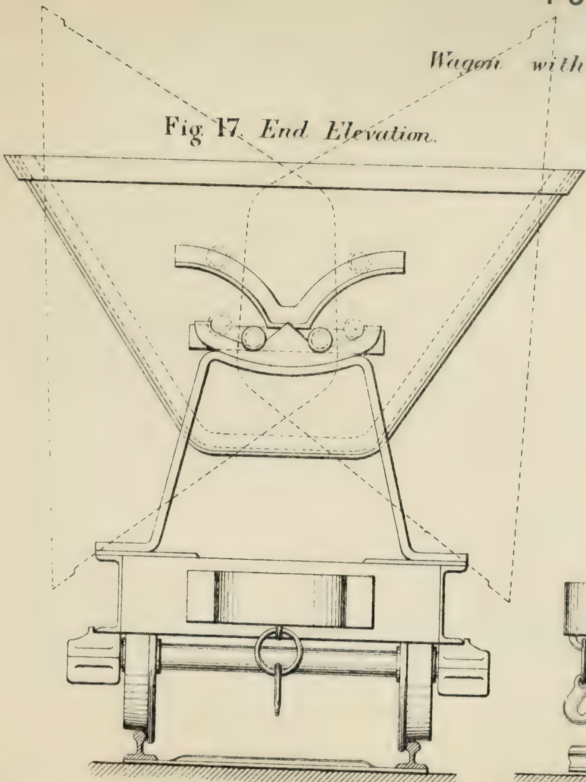
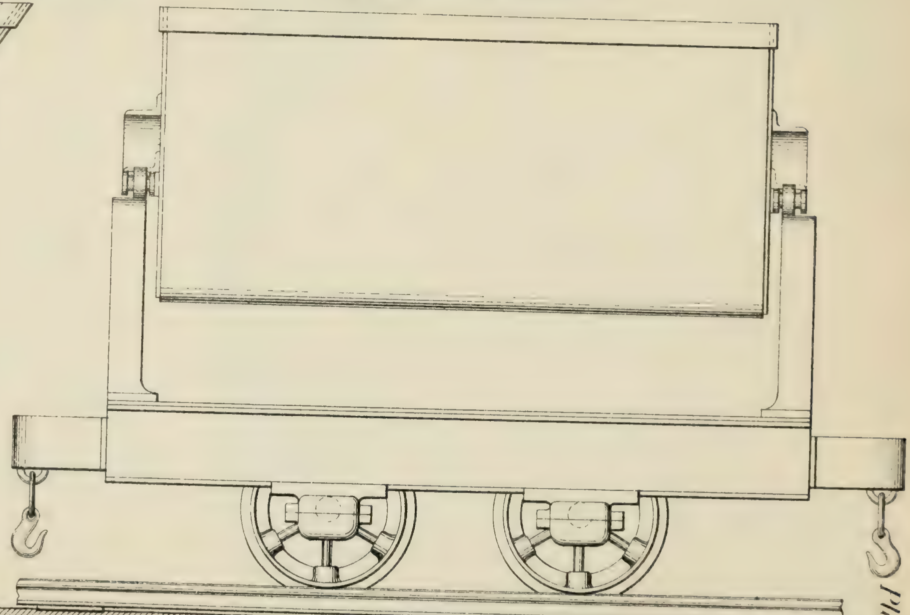


Fig. 18. *Side Elevation.*



Ins. 12 6 0 1 2 3 4 5 *Feet.*

Fig. 20. *Inspector's Carriage for Channel Tunnel.*

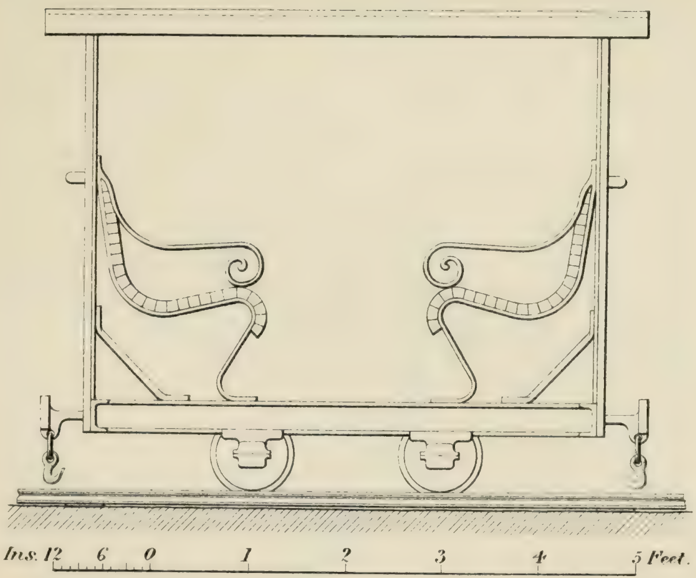
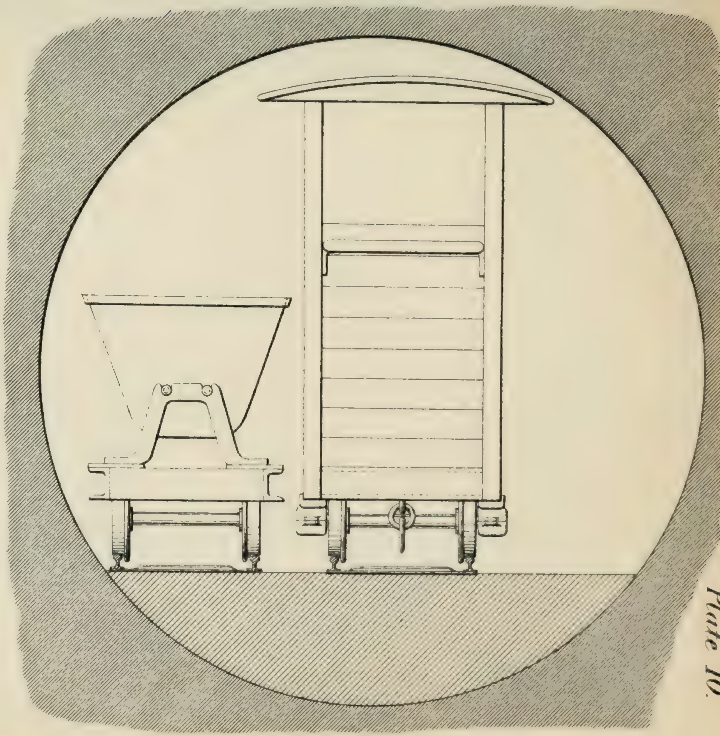


Fig. 19. *Section of Channel Tunnel.*



(Proceedings Inst. M.E. 1884.)

Scale 1/24th

Plate 10.

PORTABLE RAILWAYS.

Campaign Passenger Carriage.

Fig. 21.

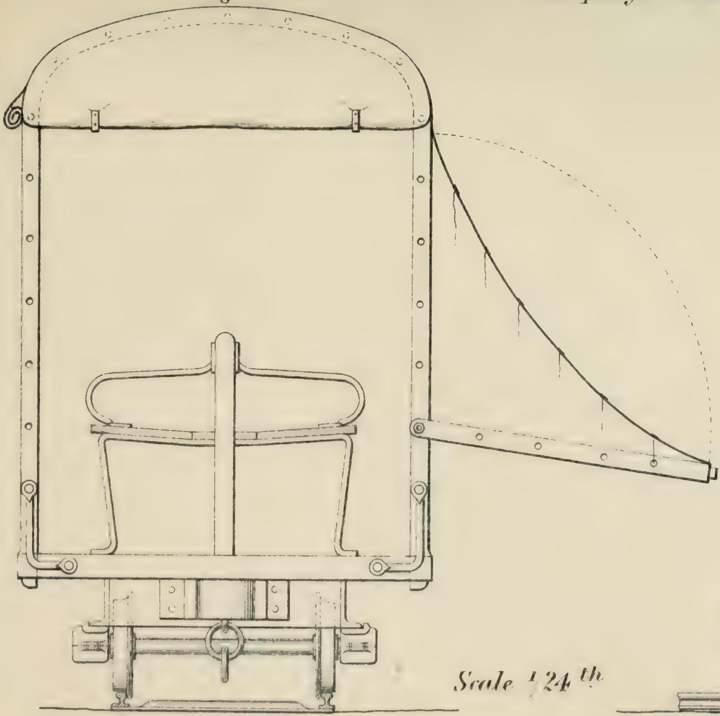
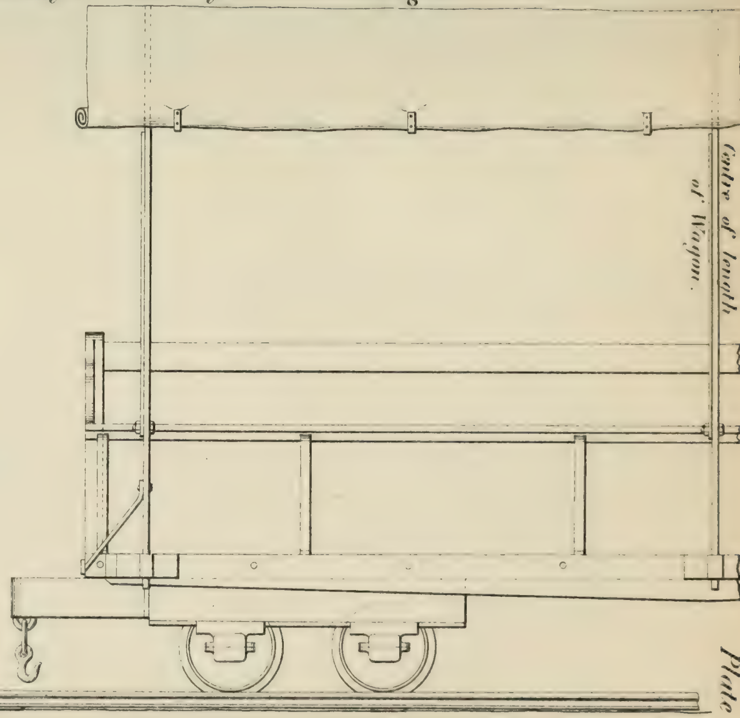


Fig. 22.



Scale 1/24 th.

Ins. 12 6 0 1 2 3 4 5 6 7 8 Feet.

(Proceedings Inst. M. E. 1884.)

Plate 11.

PORTABLE RAILWAYS.

Ambulance Wagon.

Fig. 23.

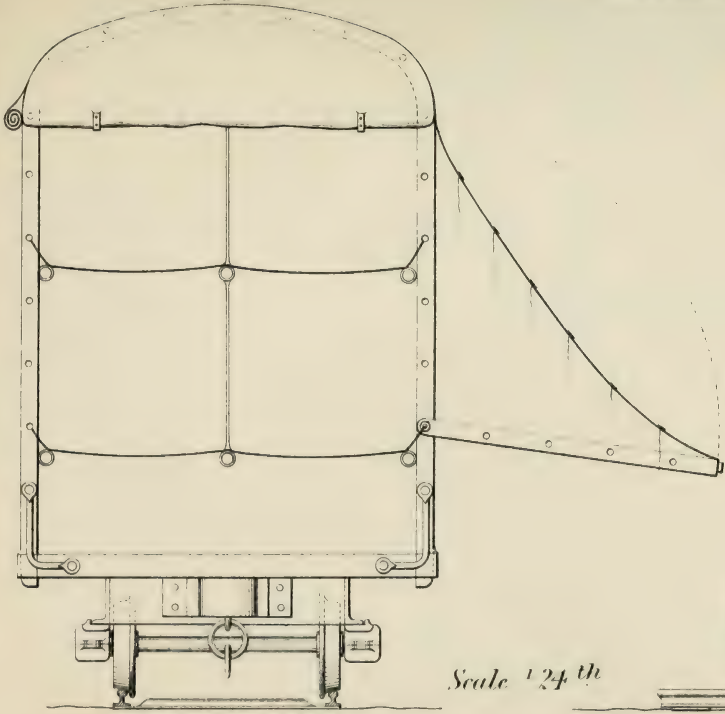
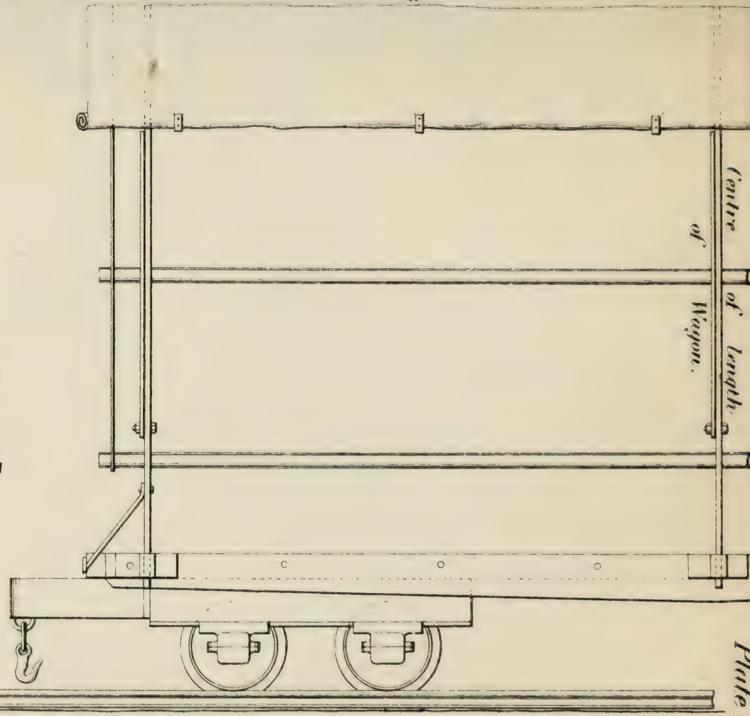


Fig. 24.



Scale 1/24th

(Proceedings Inst. M. E. 1884.)

Plate 12.

Fig. 25. *Composite Passenger Carriage.*

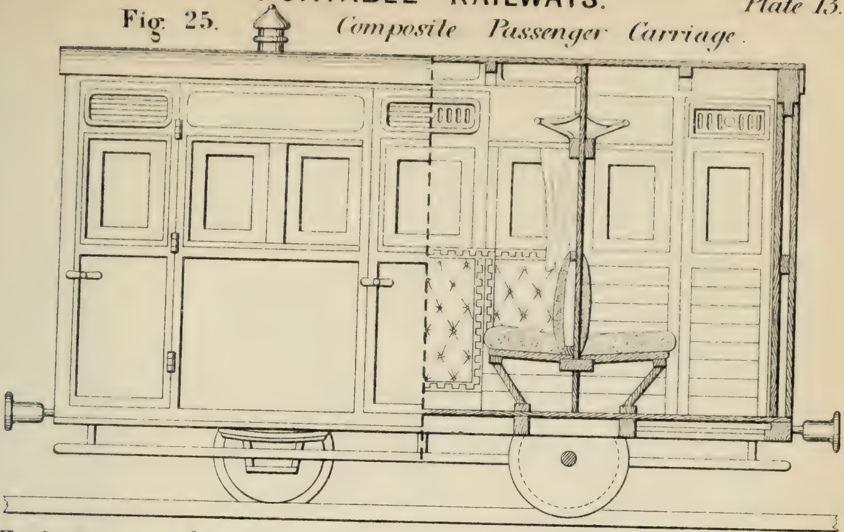


Fig. 26. *Transverse Section.*

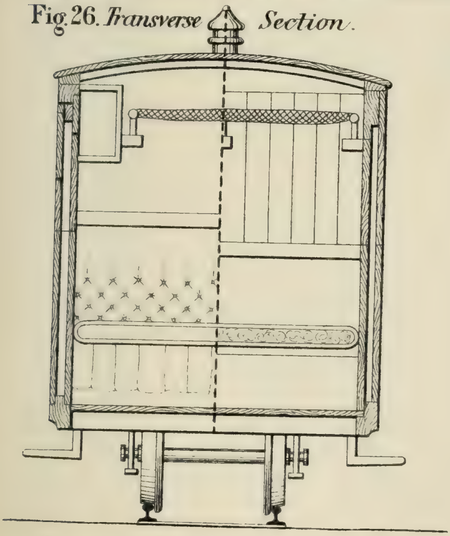


Fig. 27. *Sugar-Cane Wagon with tipping cradle. End Elevation.*

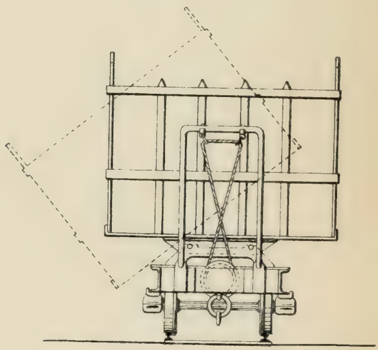
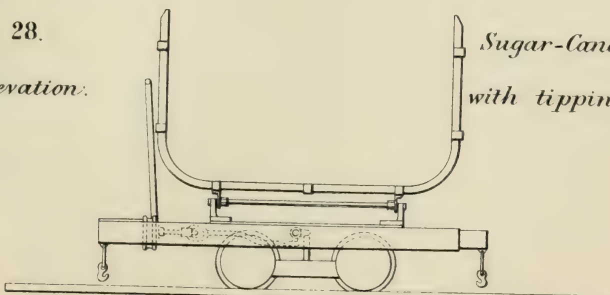


Fig. 28. *Side Elevation.*

Sugar-Cane Wagon with tipping cradle.



Ins. 12 6 0 1 2 3 4 5 6 Feet. *Scale 1/40th.*

(Proceedings Inst. M. E. 1884.)

PORTABLE RAILWAYS.

Plate 14.

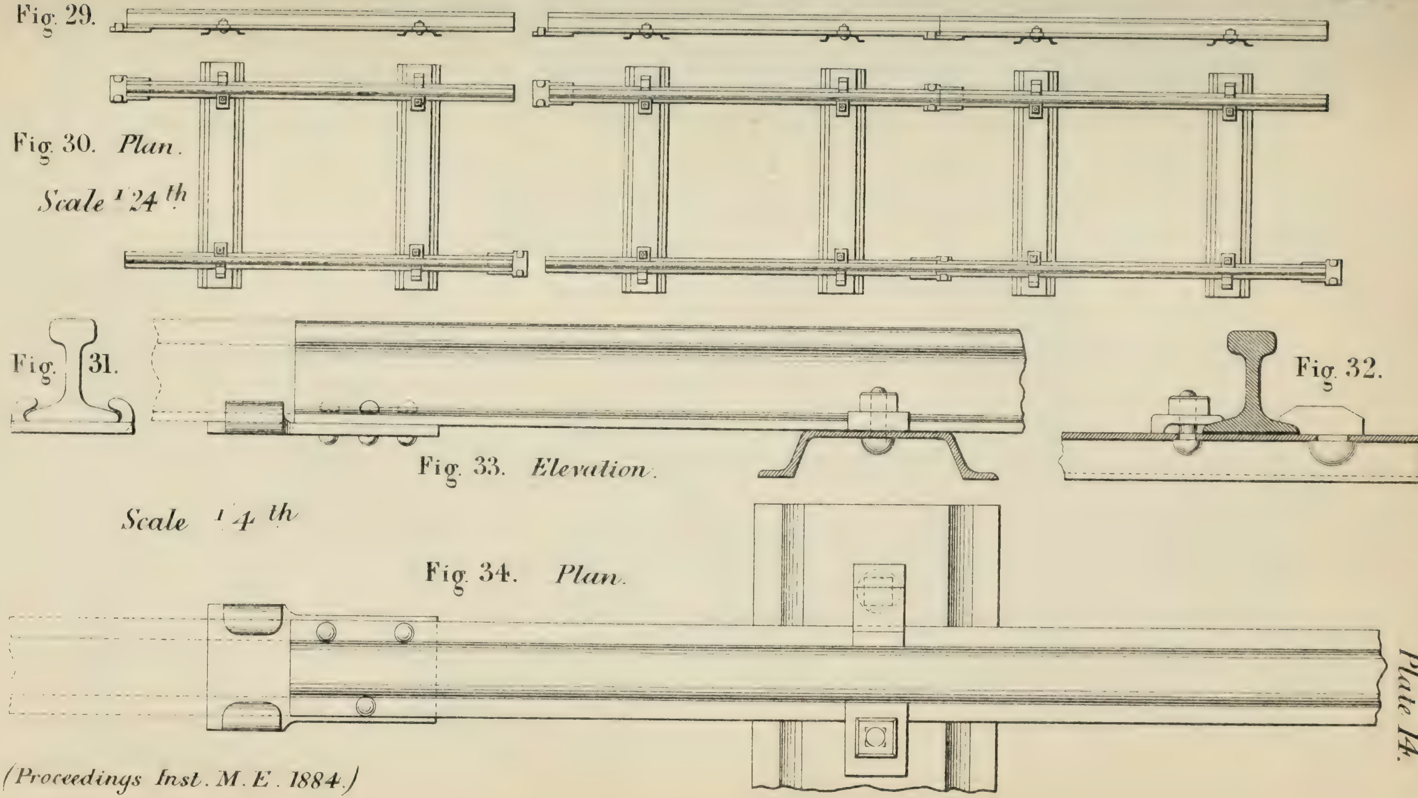


Fig. 29.

Fig. 30. *Plan.*

Scale 1/24th.

Fig. 31.

Fig. 32.

Fig. 33. *Elevation.*

Scale 1/4th

Fig. 34. *Plan.*

(Proceedings Inst. M. E. 1884.)

Plate 14.

ENGINE RECORDER.

Plate 15.

Fig. 1.
Vertical Section.
Scale 1/6th.

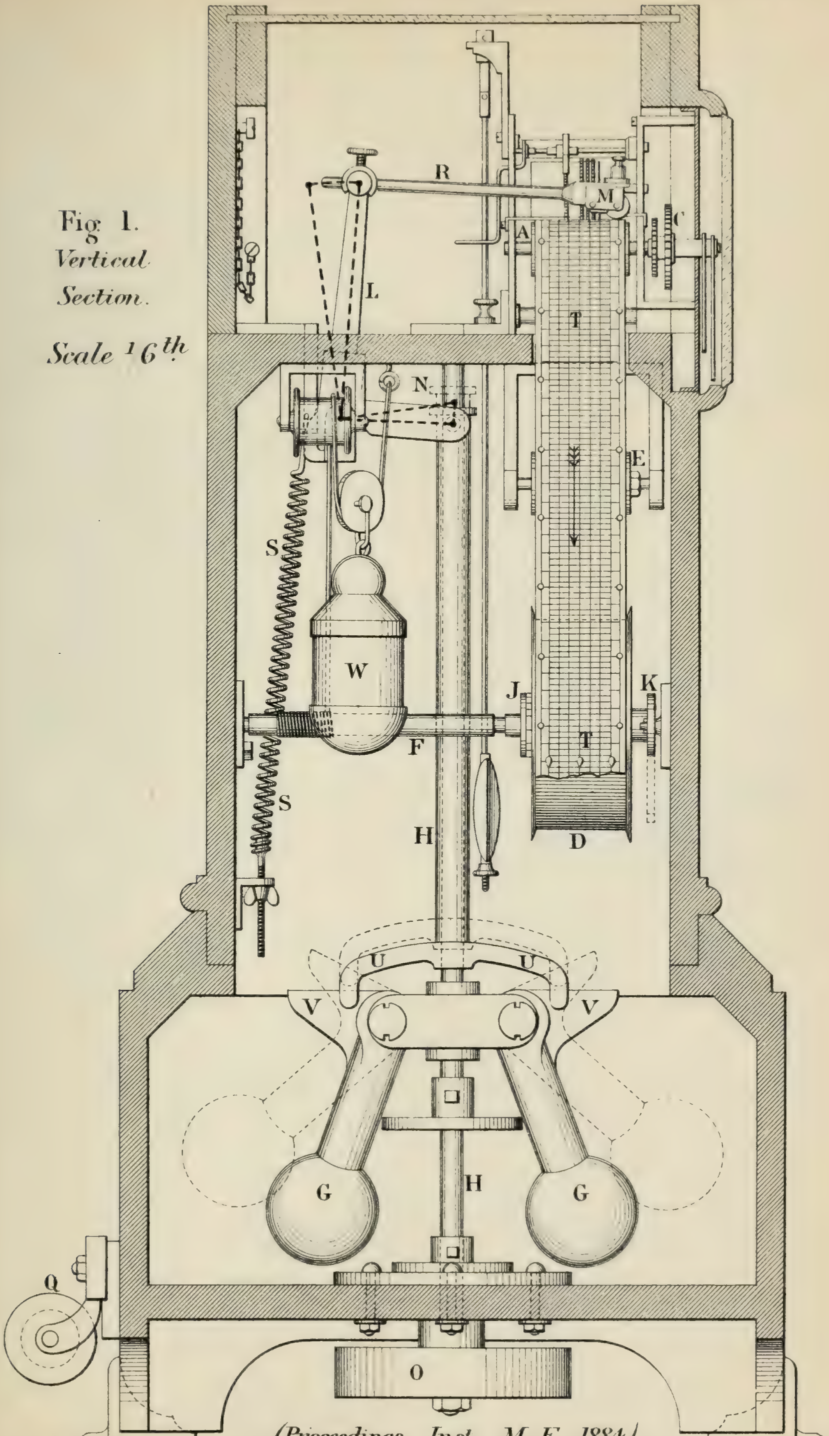


Fig. 2. *Transverse Vertical Section.*

Scale 1/6th

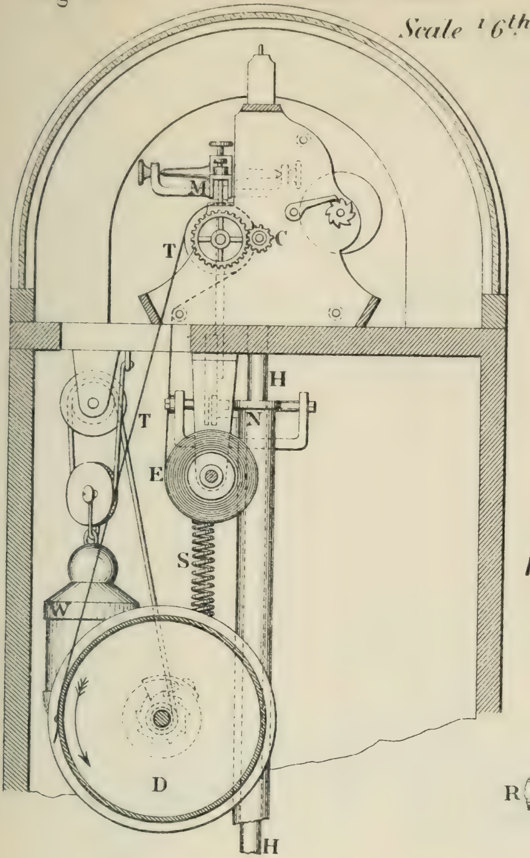


Fig. 3.
Recording Drum.
Half full size.

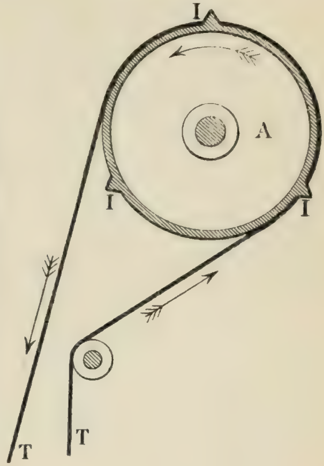


Fig. 4. *Marker*

Half full size.

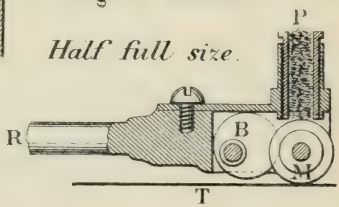


Fig. 5. *Supplementary Governor.*

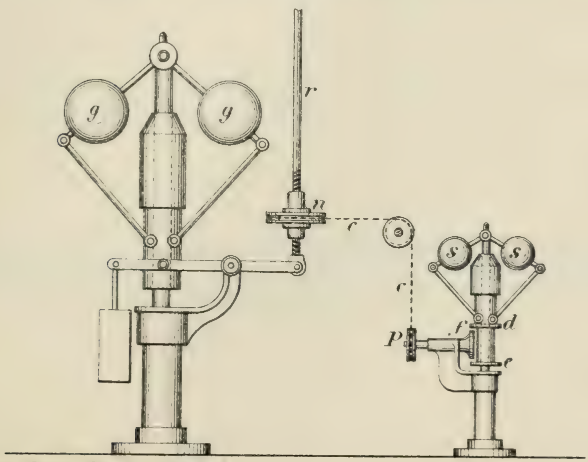
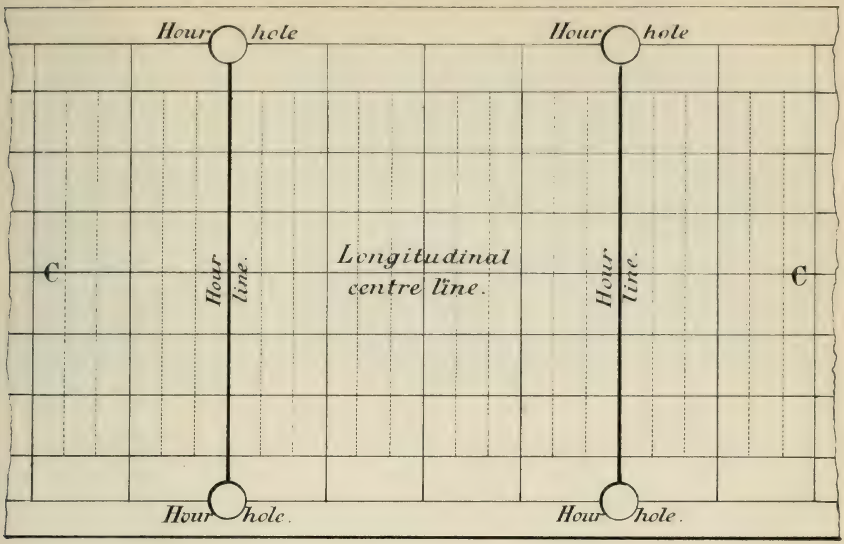
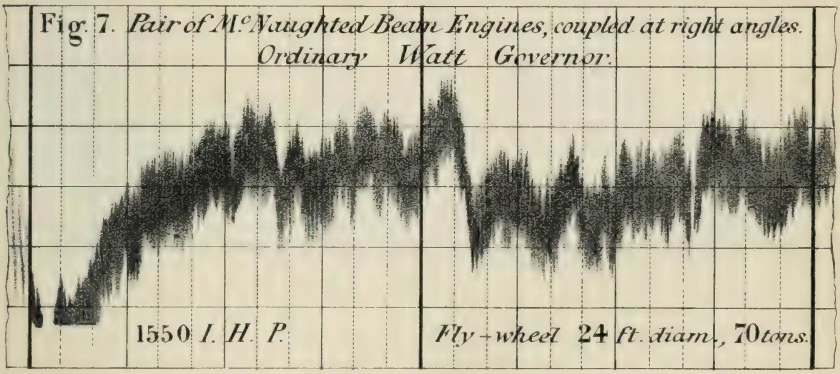
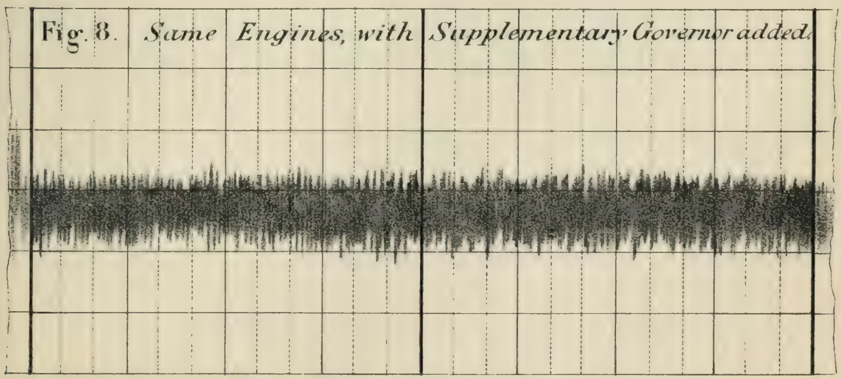


Fig. 6. *Paper Tape, as ruled for Recorder diagrams.*







(*Proceedings Inst: M. E. 1884.*) *Full size.*

Fig. 9. *M^c Naughted Beam Engine.* $28\frac{1}{2}$ *revs.* 22 *ton fly-wheel.* 410 *I.H.P.*

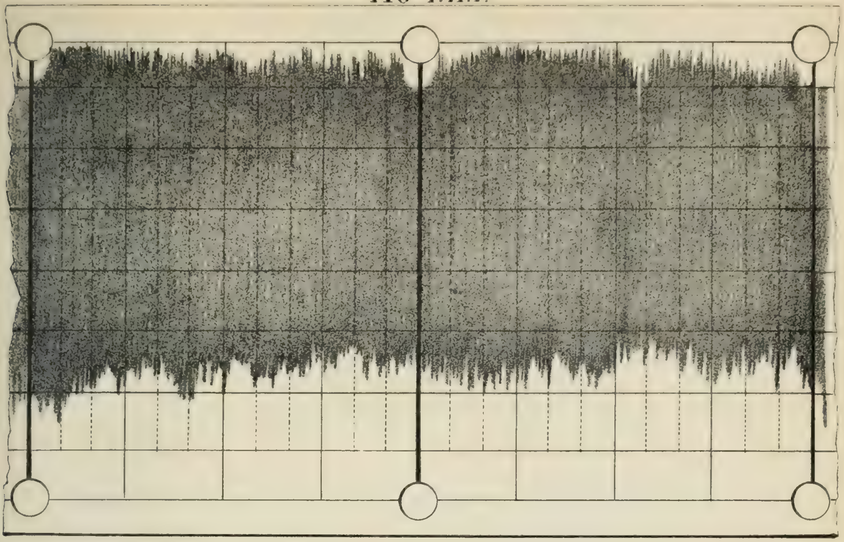


Fig. 10. *Same Engine.* 33 *revs.* 32 *ton fly-wheel.*

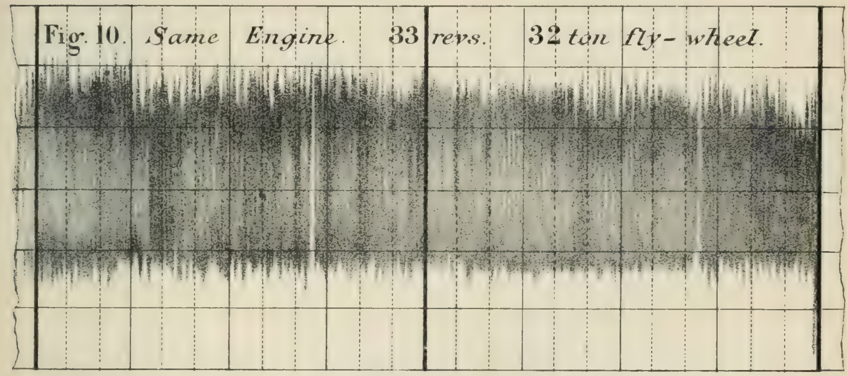


Fig. 11. *Corliss Engine.* $46\frac{1}{2}$ *revs.* 800 *I. H. P.*
Belt drum 30 *feet diam.,* 70 *tons weight.*

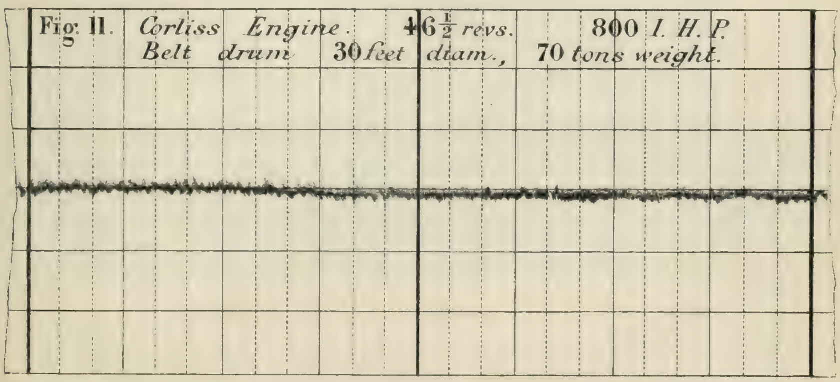


Fig. 12. *Corliss Engine. Hot main-shaft neck.*

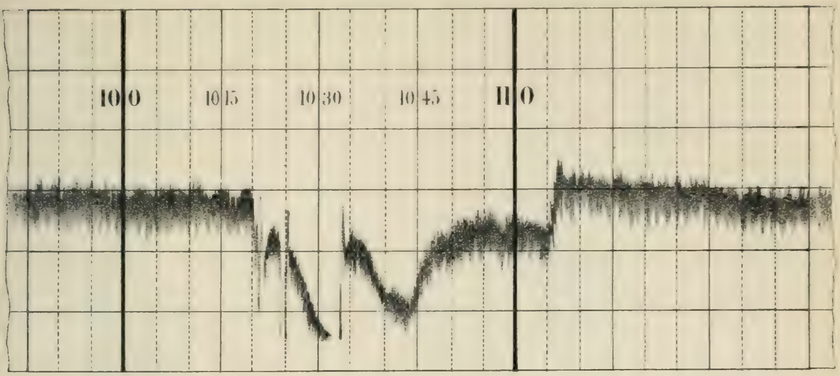


Fig. 13. *Diagram opened out by accelerating the tape.*

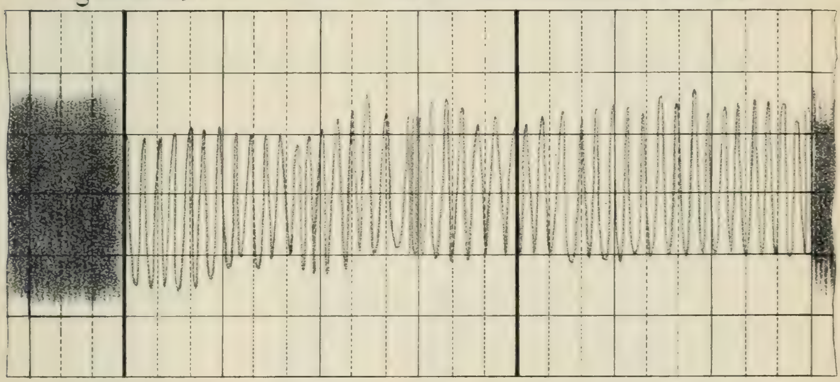
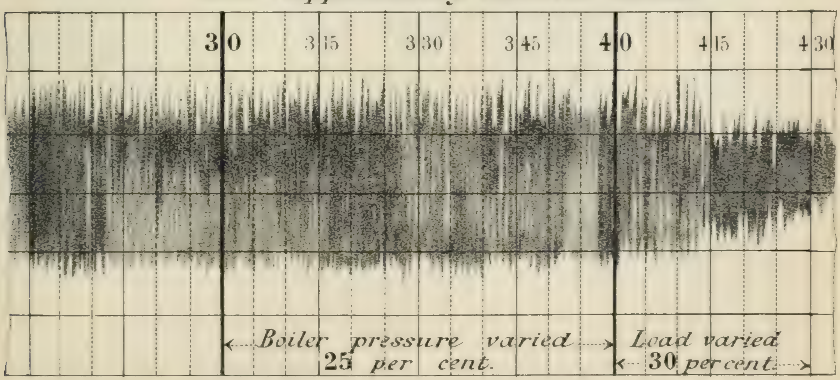


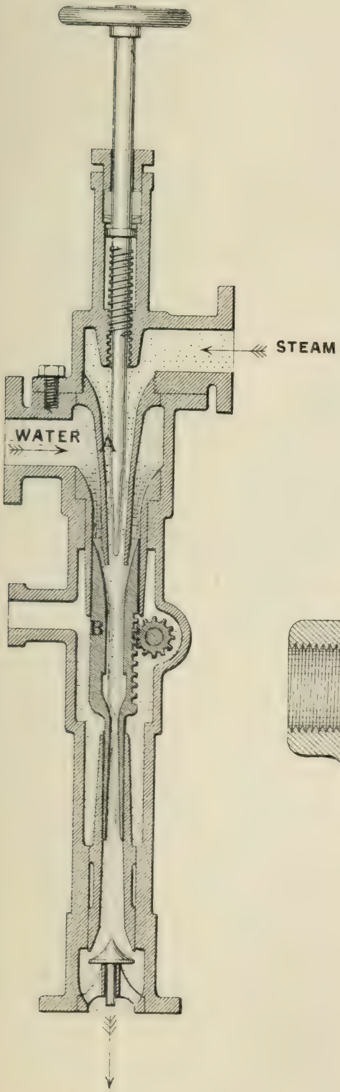
Fig. 14. *Mc Naughted Beam Engine,* 33 *revs.* 32 *ton fly-wheel, with Supplementary Governor added.*



(Proceedings Inst. M. E. 1884) *Full size.*

AUTOMATIC INJECTOR.

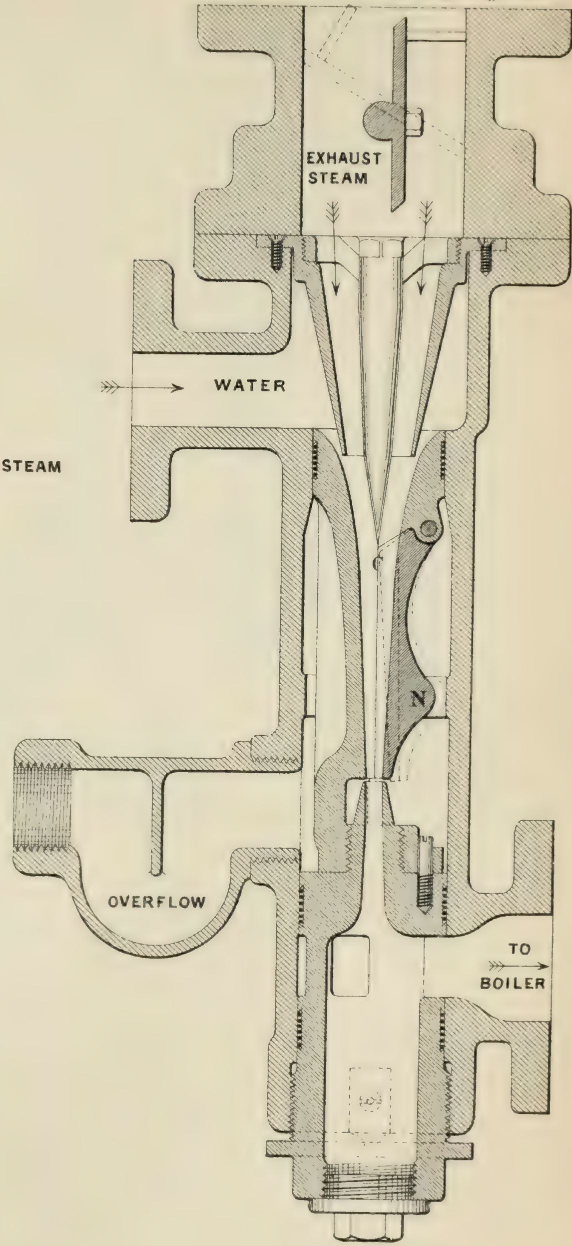
Fig. 1.
Ordinary Lifting Injector.



Scale 1/10th

(Proceedings Inst. M. E. 1884.)

Fig. 2.
Automatic Re-starting Injector.



Scale 1/3rd

Fig. 3. *Split Nozzle in Live-Steam Injector.* *Full size.*

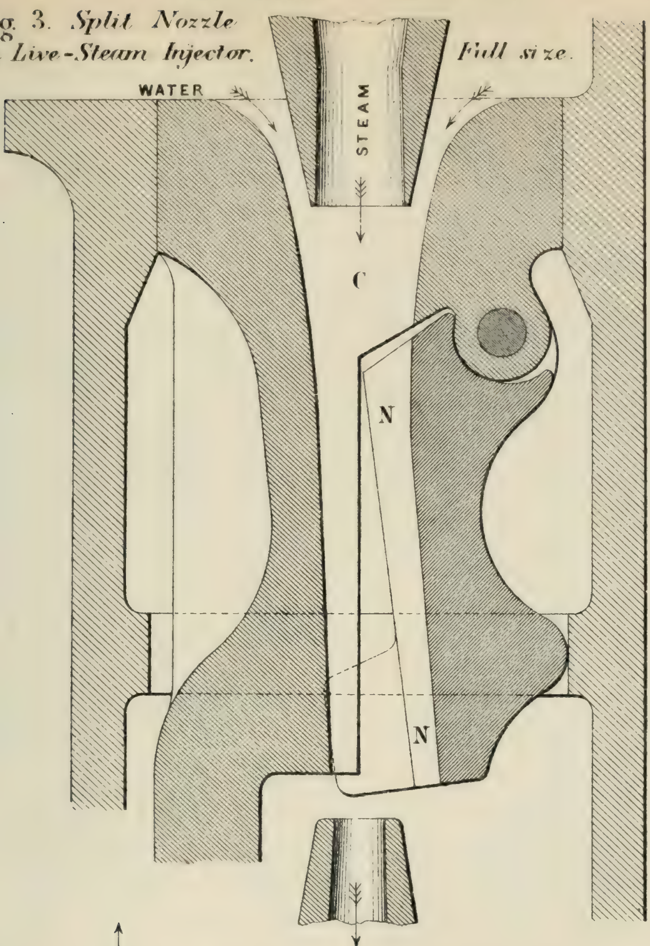
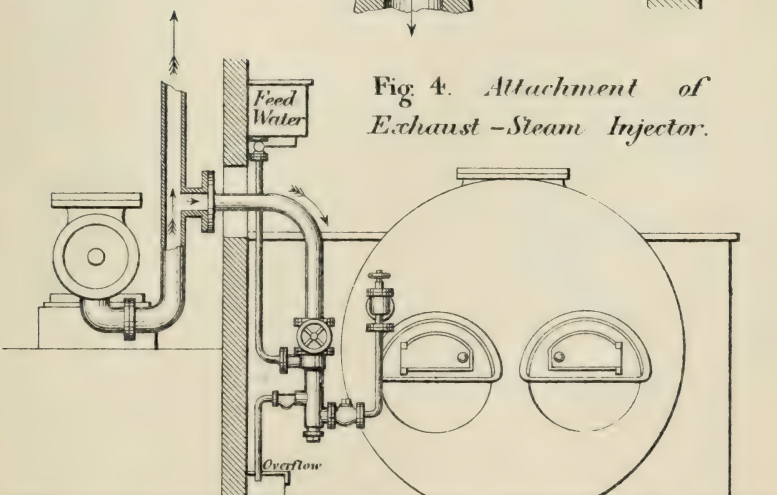


Fig. 4. *Attachment of Exhaust-Steam Injector.*



 Scale 1/48th

AUTOMATIC INJECTOR. *Plate 22.*

Split Nozzle in Exhaust-Steam Injector.

Longitudinal Sections.

Fig. 5. *Flap open.*

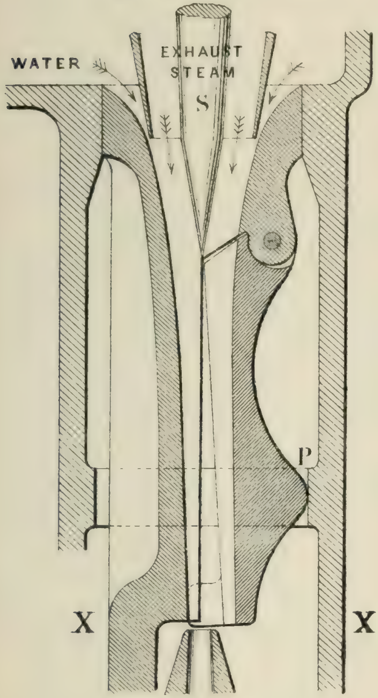


Fig. 7. *Flap shut.*

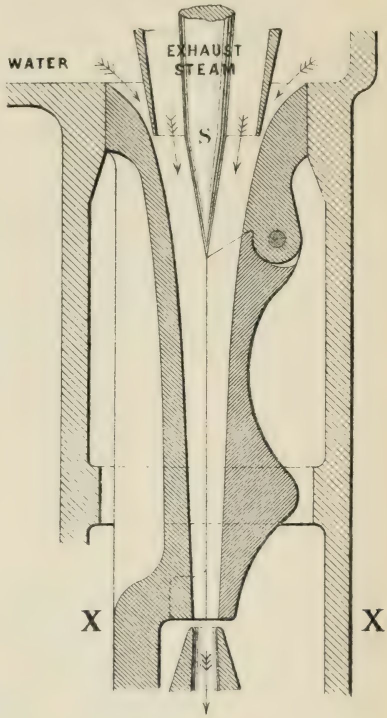
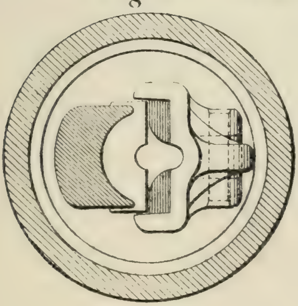
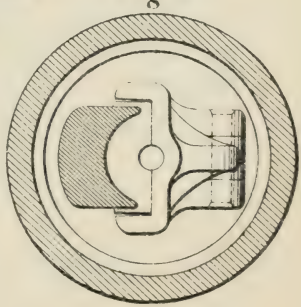


Fig. 6. *Transverse Sections* *(inverted)* *at* XX. Fig. 8.





Scale half full size.

(Proceedings Inst. M.E. 1884.)

EXHAUST-STEAM INJECTOR.

Fig. 9.

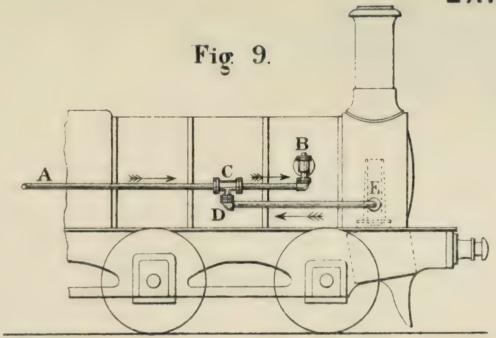


Fig. 10.

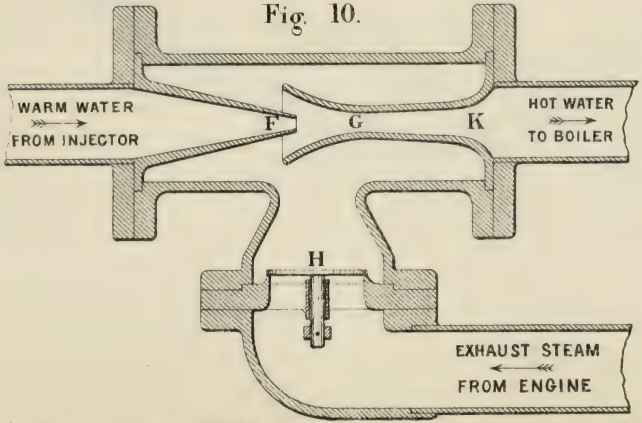


Fig. 11.

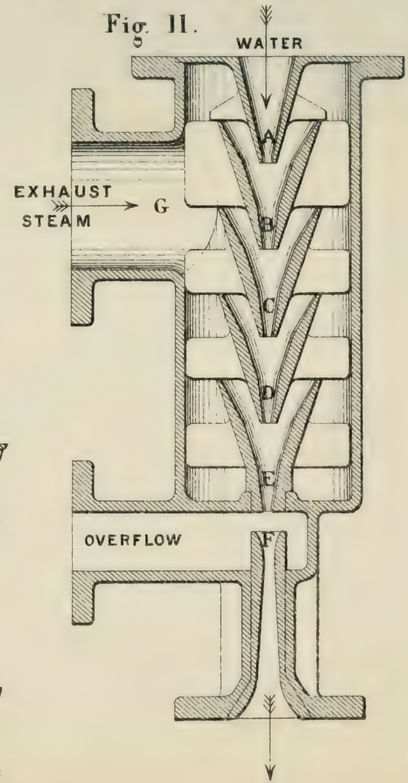
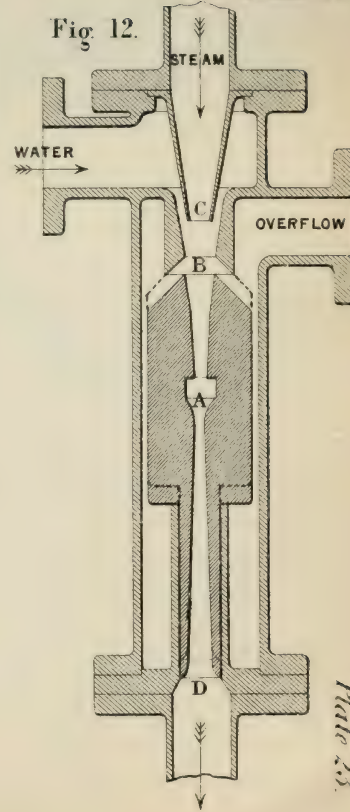


Fig. 12.



(Proceedings Inst. M. E. 1884.)

Plate 23.

TESTING CURRENT-METERS.

Plate 24.

Testing Tank.

Fig. 2. *Transverse Section at middle of Tank.*

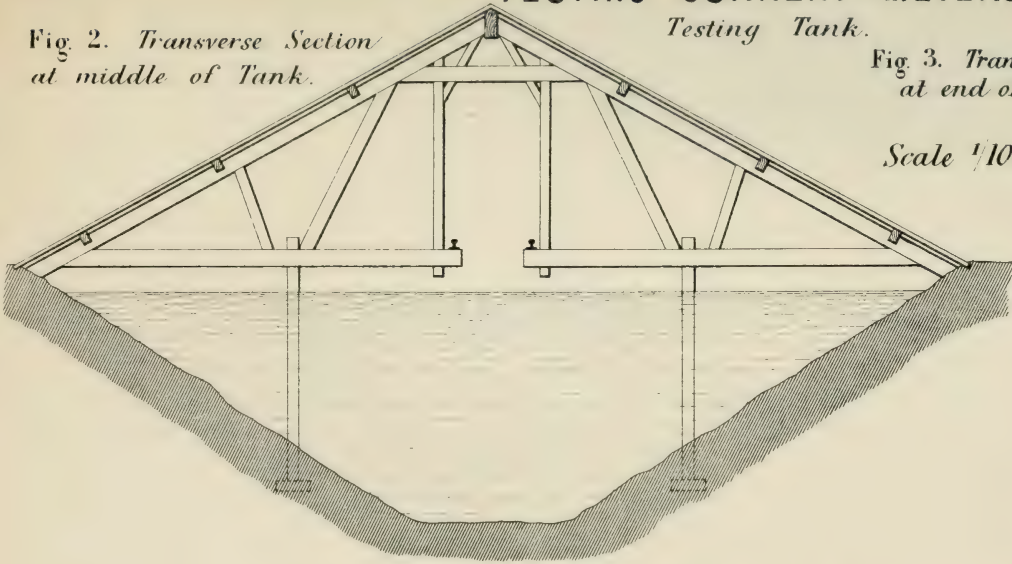
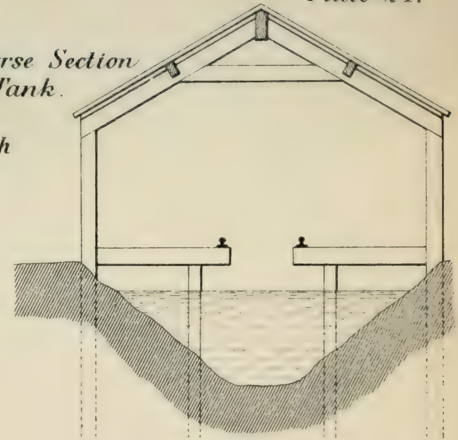
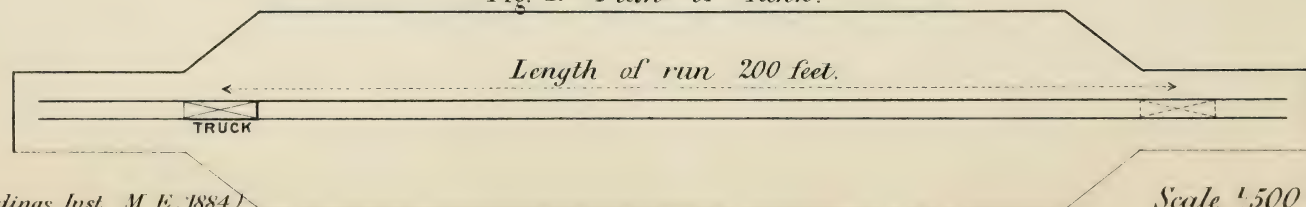


Fig. 3. *Transverse Section at end of Tank.*



Scale 1/100th.

Fig. 1. *Plan of Tank.*



Scale 1/500th.

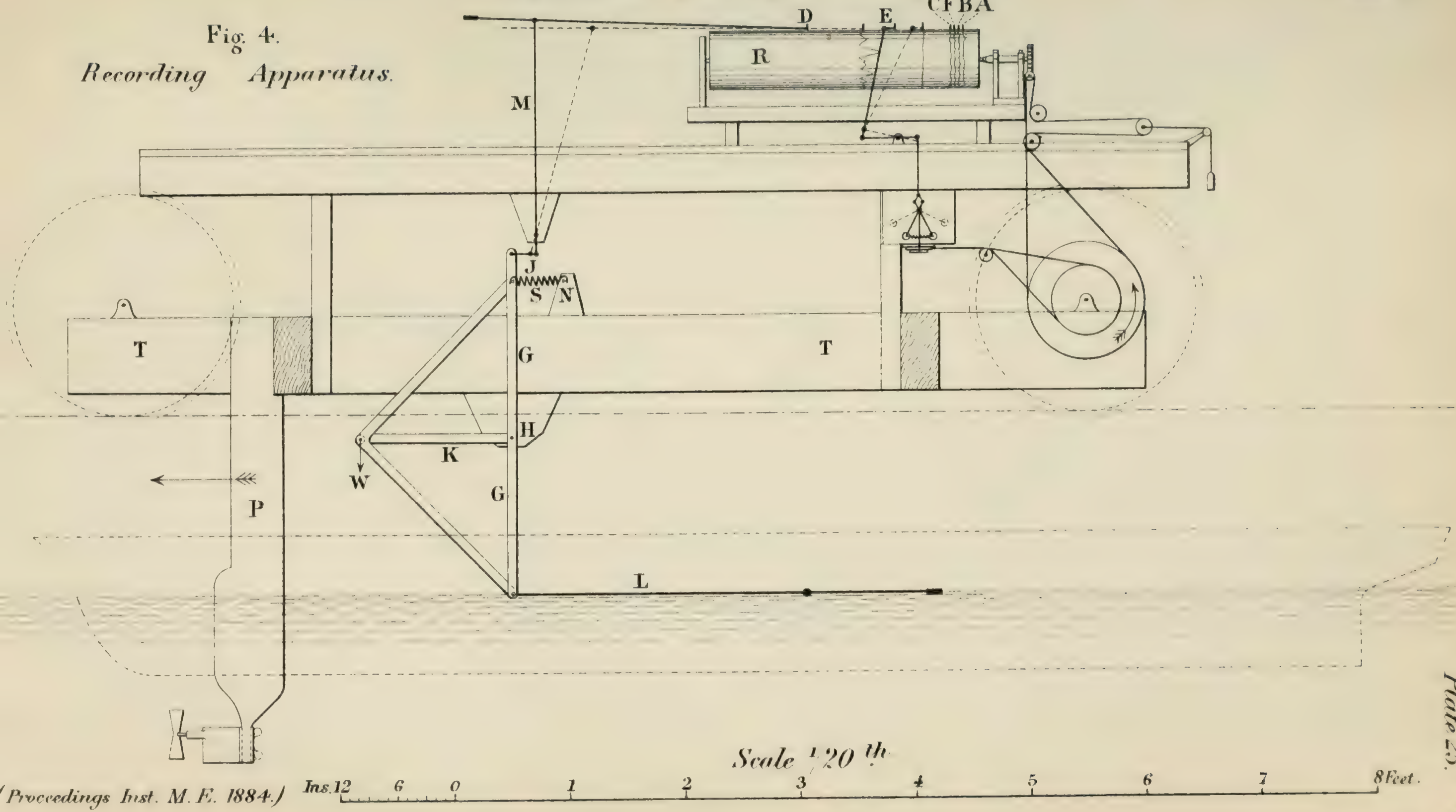
Plate 24.

(Proceedings Inst. M. E. 1884.)

TESTING CURRENT-METERS.

Fig. 4.

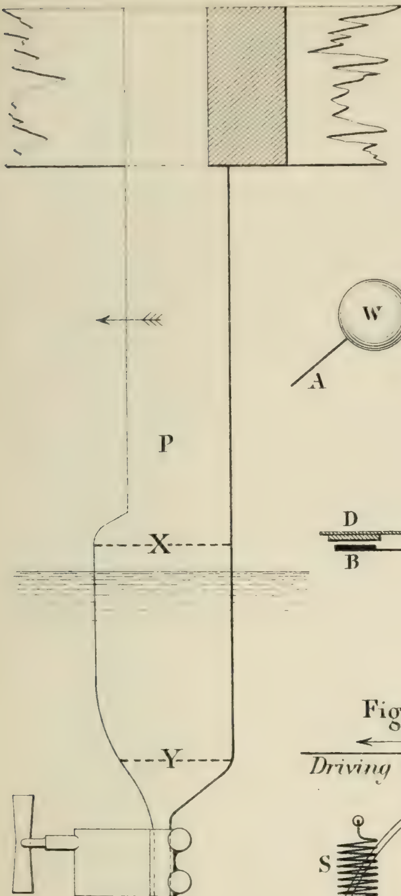
Recording Apparatus.



(Proceedings Inst. M. E. 1884.)

Plate 25.

Fig 5. *Meter Carrier.*



Section at X.

Section at Y.

Scale 1/10th.

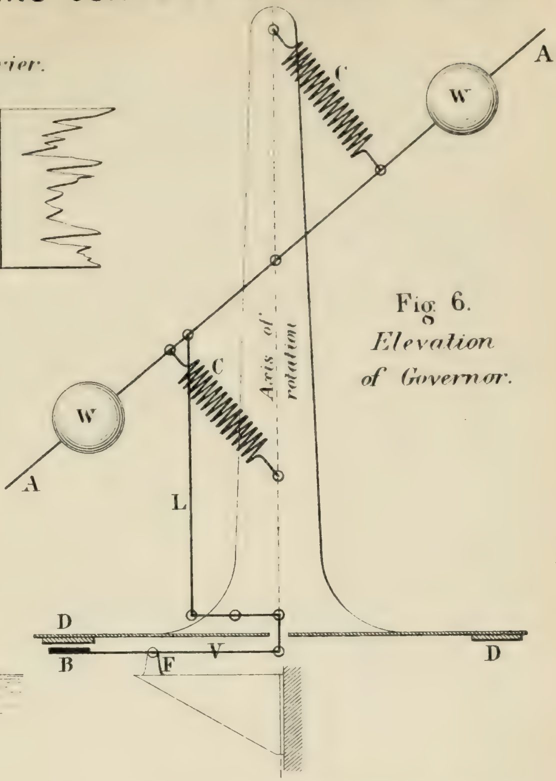
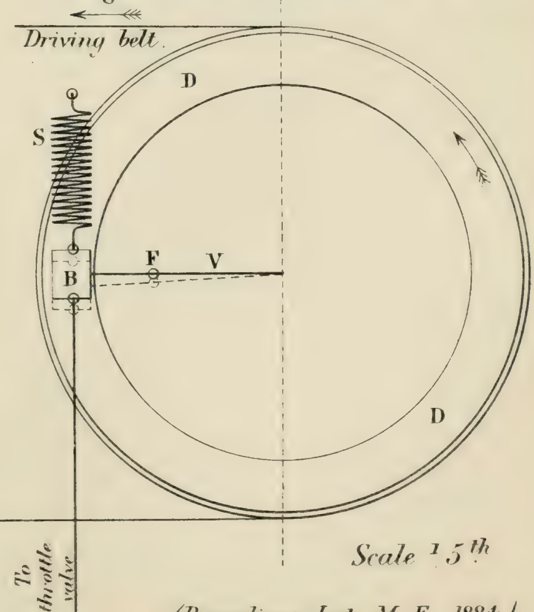


Fig 6. *Elevation of Governor.*

Fig 7. *Plan of underside of disc.*



Driving belt.

Scale 1/5th.

Fig. 8. *Records from experiments with small meter. Full size.*

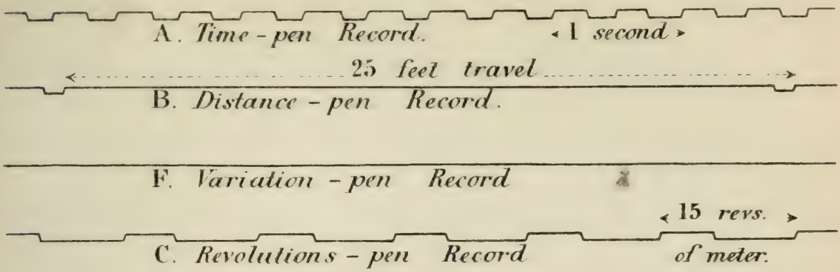


Fig. 9. *Dynamometrical-pen Records. Full size.*

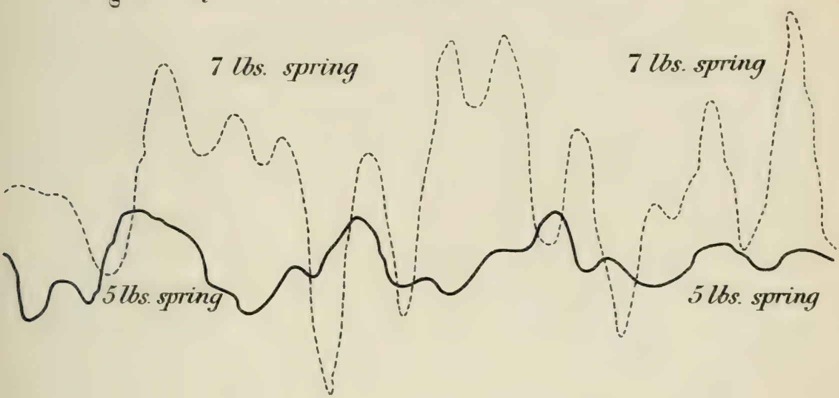
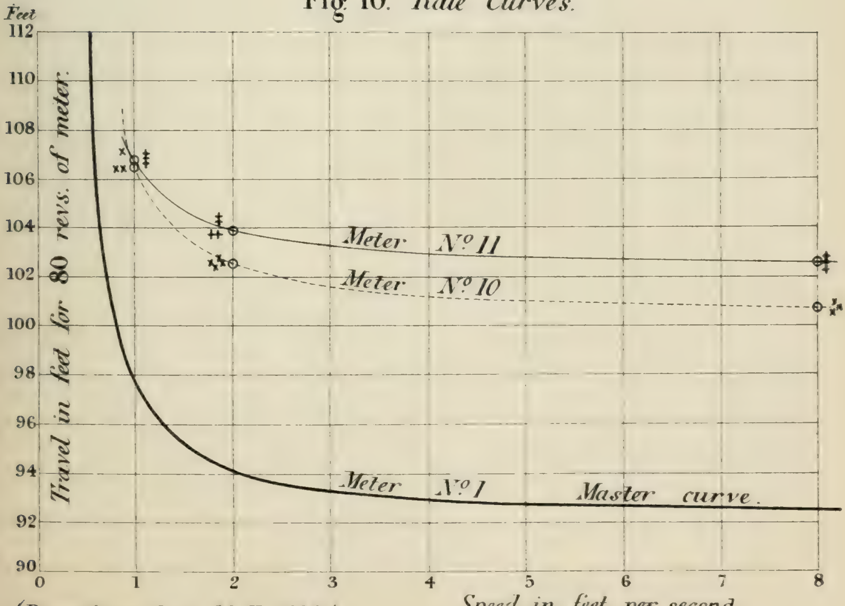


Fig. 10. *Rate Curves.*



Institution of Mechanical Engineers.

PROCEEDINGS.

August 1884.

The Summer Meeting of the Institution was held at Cardiff, commencing on Tuesday, 5th August 1884, at Ten o'clock a.m.; I. Lowthian Bell, Esq., F.R.S., President, in the chair.

The Members were received by the Mayor of Cardiff, Robert Bird, Esq., in the Lecture Theatre of the Cardiff Public Hall.

The Mayor said it devolved upon him to have the very great pleasure of giving the Institution of Mechanical Engineers a hearty welcome to Cardiff, on behalf of the inhabitants of the town. It was to them a source of pride that so distinguished an Institution should visit them; and he hoped the visit would not only be pleasant to the Members, but would also be productive of important results in connection with those matters with which they were all intimately associated. This was not the time for speech-making, otherwise he might be disposed to occupy a little of their attention; it was now his sole duty to assure the Institution of a very hearty welcome to Cardiff; and he trusted that the bright morning which now dawned upon the commencement of their Meeting was an earnest that they would enjoy fine weather throughout the rest of their week's visit.

The President said that on behalf of the Members of the Institution of Mechanical Engineers he wished to thank the Mayor very cordially for his hearty welcome. That South Wales enjoyed a high character for its hospitality had been proved on many occasions. When the British Association met at Swansea a few years ago, and when the Iron and Steel Institute, in the second year of its existence, met at Merthyr Tydvil, they were received in the

kindest manner by the inhabitants and leading persons connected with this great district. That South Wales enjoyed that character was further proved by the circumstance of so many Members of the Institution of Mechanical Engineers assembling on the present occasion. He again desired to thank the Mayor very sincerely for his most cordial reception.

The Minutes of the previous Special and General Meetings were read, approved, and signed.

The President announced that the Ballot Lists for the election of New Members had been opened by a Committee of the Council, and the following fifty-three candidates were found to be duly elected:—

MEMBERS.

Alfred Evans Allen,	Hull.
Samuel Wesley Allen,	Cardiff.
Frank Ashwell,	Leicester.
George John Beetlestone,	Penarth.
James Johnstone Bourne,	Wallington.
William B. Bryan,	London.
Thomas Bunt,	Shanghai.
Joseph John Butcher,	Newcastle-on-Tyne.
John Chamberlain,	London.
Ralph Collenette,	Barrow-in-Furness
James Colquhoun,	Tredegar.
John Charles Coltman,	Loughborough.
George Alexander Corder,	Amoy.
Alfred Herbert Davies,	Nottingham.
John Donnelly,	London.
David Evans,	Rhymney.
George Fisher,	Cardiff.
Edwin Frampton,	London.
James Ker Gulland,	London.
Harold Hayes Harker,	Rio de Janeiro.
Hippolyte Josse,	Paris.

James Kerr, ...	London.
William Thomas Lewis, . . .	Aberdare.
Archibald Robert Mackintosh, .	Newcastle-on-Tyne.
Reginald Empson Middleton, . .	South Queensferry.
George A. Mower, ...	London.
John Nelson, ...	York.
James Mayne Nicholls, . . .	Iquique.
Thomas Head Nicholson, . . .	Newcastle-on-Tyne.
William Parlane, ...	Hong Kong.
Frank Henry Pearson, . . .	Hull.
George Williams Penn, . . .	Cardiff.
William Claude Rafarel, . . .	Barnstaple.
William David Rees, . . .	Swansea.
William Thomas Rees, . . .	Aberdare.
Charles Hurry Riches, . . .	Cardiff.
John Scott, ...	Bristol.
William Stopford Smyth, . .	Newport, Mon.
Joseph Wilson Swan, ...	London.
Arthur Hirst Thwaites, . . .	Bradford.
Illius Augustus Timmis, . . .	London.
Thomas Waters Wailes, . . .	Cardiff.
John Wallace, ...	Newcastle-on-Tyne.
John Henry Whieldon, . . .	Nottingham.
John Rhys Williams, ...	Rhymney.
Alexander Wilson, ...	London.
Henry Withy, ...	West Hartlepool.

ASSOCIATES.

Paul Nooncree Hasluck, . .	London.
Joseph Montague Livesey, . . .	Thames Ditton.

GRADUATES.

Frank Adam, ...	Newcastle-on-Tyne.
Paul S. Roux, ...	Paris.
Maurice Taylor, ...	London.
Ralph Teasdale Walker, . . .	London.

The President then delivered his Address: after which the following papers were read and discussed:—

On recent extensions of Dock Accommodation and Coal-Shipping Machinery at the Bute Docks, Cardiff; by Mr. John McConnochie, of Cardiff.

Description of the new Locomotive Running Shed of the Taff Vale Railway at Cathays, Cardiff; by Mr. Charles H. Riches, of Cardiff.

Description of the Francke "Tina" or Vat Process for the Amalgamation of Silver Ores; by Mr. Edgar P. Rathbone, of London.

At One o'clock the Meeting was adjourned to the following morning.

The Adjourned Meeting was held in the Lecture Theatre of the Cardiff Public Hall, Cardiff, on Wednesday, 6th August 1884, at Ten o'clock a.m.; I. Lowthian Bell, Esq., F.R.S., President, in the chair.

The following papers were read and discussed:—

On the use of Petroleum Refuse as Fuel in Locomotive Engines; by Mr. Thomas Urquhart, of Borisoglebsk, Russia.

On the Causes and Remedies of Corrosion in Marine Boilers; by Mr. J. Harry Hallett, of Cardiff.

The President proposed the following Votes of Thanks, which were seconded by Mr. Head, and passed by acclamation:—

To the Most Honourable the Marquess of Bute, the Right Honourable Baron Windsor, the Mayor of Cardiff, Mr. George T. Clark, the Ebbw Vale Company, the Patent Nut and Bolt Company, Mr. Thomas A. Walker, and the other gentlemen who have extended so handsome and hospitable a welcome to the Members of the Institution on the occasion of the present Meeting in Cardiff.

To the Proprietors of the various Collieries and Ironworks, and the numerous Engineering and other Works in Cardiff and Newport and the surrounding district, for their kindness in opening their Works to the Members, and for the arrangements obligingly made in connection with their visit.

To the authorities of the Taff Vale, Rhymney, Brecon and Merthyr, Great Western, and London and North Western Railways, for the facilities they have so kindly afforded by offering Special Trains for the Excursions.

To the Local Committee, and especially to the four Executive Officers—the Chairman, Mr. Wm. Thomas Lewis; the Vice-Chairman, Mr. John McConnochie; the Honorary Treasurer, the Mayor of Cardiff; and the Honorary Secretary, Mr. Tom Hurry Riches—for the admirable arrangements they have made for the present Meeting, and the hospitable reception they have prepared for the Members.

Mr. T. Hurry Riches said it always afforded the engineers of South Wales and their friends a great deal of pleasure to welcome to that district the Institution of Mechanical Engineers or any other equally eminent association.

The Meeting then terminated.

ADDRESS OF THE PRESIDENT,

I. LOWTHIAN BELL, ESQ., F.R.S.

GENTLEMEN,—Before deciding on the choice of a subject upon which I should say something to you upon the present occasion, I naturally turned my attention to the very able addresses which have been delivered by my distinguished predecessors in this chair. In the list — and not the least comprehensive and interesting of the number—is one by Sir Frederick Bramwell. Among the various important services rendered by the Mechanical Engineer, he claims that of having brought into existence the Civil Engineer, to whose profession the world is so much indebted.

The object of my search was to select a subject which would afford me some hope of justifying, partially at all events, your having invited me to occupy a position which has been filled by some of the ablest mechanical engineers of the day. I will not enlarge upon the misgivings with which I approached the task, more than to assure you that they have added greatly to the difficulty of thanking you in commensurate terms for the high honour you have conferred upon me.

I purpose addressing you on a metal—Iron—of which it is not too much to say that its existence constitutes a condition precedent to the very origin of both the engineering sciences already referred to. This, and the circumstance of our meeting in one of the oldest seats of the British iron trade, will, I trust, reconcile you to the selection I have made of the subject for my discourse. To myself it is one which particularly recommends itself, less from my long association with it than from its affording me an opportunity of acknowledging how immensely the manufacture of iron is indebted for its marvellous progress in recent years to the assistance it has received from the hands of the mechanical engineer.

The Dowlais Iron Company, with their accustomed liberality and kindness, will open their works for our inspection. In that renowned establishment, you will find a blowing-engine delivering its blast from a cylinder twelve feet in diameter, with a stroke of the same length. You will also have an opportunity of beholding a rail-mill engine on the Ramsbottom direct-action principle, the largest of its kind in the world. Now it is no exaggeration to say that the existence of such pieces of machinery as these would have been a physical impossibility for many years after the beginning of the present century. Of the sober truth of this statement you may judge when I mention that I was informed many years ago by the late manager of the celebrated Wallsend Colliery of the difficulty he experienced upon one occasion in obtaining a steam-engine cylinder of about two feet in diameter. At that time, probably about the year 1810, there was not an ironfoundry on the Tyne capable of casting it, nor a tool in the Northern counties fit for boring it. Ultimately a more enterprising firm in Scotland was persuaded to undertake the work on being permitted to cast it in two pieces, and, in addition, on being allowed to fill up with tram rails the sloop which conveyed it to Wallsend.

When a spectator finds himself in the midst of such triumphs of mechanical engineering as are now to be seen in every well-appointed ironwork, he must be apt to associate the manufacture of iron with the presence of vast mechanical force. Nevertheless there is no metal capable of being separated from the mineral containing it by simpler means than the one we are considering. Our ancestors supplied their wants by forming a small heap of ore and charcoal on an exposed hill-side. There unassisted Nature performed the office of a blowing-engine; and with one stone for the hammer, and another for the anvil, as much iron was obtained as served for a people who largely depended on the chase for their subsistence.

We have no record of the date at which we, in this country, emerged from the state of being dependent for the iron we required on such primitive forges as those just mentioned. We do know however that for many centuries, probably until the fifteenth, piles of rough masonry, enclosing a cavity of six or eight cubic feet,

into which air was blown by the simplest form of bellows, performed the duty now demanding the help of the powerful and complicated machinery so familiar to every one in this meeting.

The advance, thanks to the mechanical engineer, in the construction of the engines employed in our ironworks has been so rapid that there are yet to be found, still in use, examples of very antiquated modes of manufacturing the metal, which have survived the quick changes introduced elsewhere. I had an opportunity of examining a case in point a short time ago, in a blast furnace built towards the end of the last century, on the great road over Mont Cenis. At the period of its erection that road was probably a mule-track: at any rate, I have myself performed less difficult journeys over Alpine passes which were inaccessible by wheels. Every one knows what a revolution has been effected in the means of carrying traffic over and through the great natural difficulties presented by the rocky summit of this mountain. The mule has given place to the locomotive, the circuitous path cut in the face of lofty precipices has been abandoned, and a tunnel, designed by the Civil Engineers and pierced by their Mechanical brethren, now permits the passage of tons where perhaps ounces were previously carried, and this at twenty times the speed of former years. Thus alongside this achievement of modern enterprise you have the blast furnace in its most ancient form, using charcoal for its fuel, blown by a current of air induced by streams of water falling down through hollowed stems of trees. I visited another equally primitive establishment in the Smoky Mountains in North Carolina. There wrought iron was being made in a Catalan fire, blown, like the blast furnace in Savoy, by the so-called *trompe*, the bloom being afterwards drawn out under a hammer very different in principle from that designed by my friend James Nasmyth.

Besides the acknowledgment of the immense services rendered by mechanical science to the art of making iron, which this brief retrospect of its progress has enabled me to offer, I have other motives in selecting that metal as the subject of the present address.

The Bessemer process has revolutionised the mode of obtaining it in its malleable form. The product is purer, and therefore better, while the cost of conversion is less than that obtained by means of the puddling furnace.

The metalloids which it is the object of both processes to remove, and which are known to injure the quality of the products, are silicon, sulphur, and phosphorus. To illustrate the superior efficiency possessed by the Bessemer converter in separating these three substances, I give their percentage in Middlesbrough pig iron, followed by their average percentage in ten iron rails and twenty steel rails manufactured from Cleveland ironstone. The former were rolled from No. 2 stabbed-down bars, and the latter from steel ingots made by the so-called basic process. These modes of treatment involve two heatings in the mill for the iron rail-head, whereas one only sufficed for the rail made of steel.

	Middlesbrough Pig.	Iron Rail-head.	Steel Rail.
Silicon, per cent. . .	1·750	0·159	0·065
Sulphur ,, . .	0·100	0·041	0·095
Phosphorus ,, . .	1·500	0·324	0·054
Total percentages .	3·350	0·524	0·214

These figures indicate that there remains in the iron rail nearly one and a half times more of the noxious elements than in the steel rail. When the puddling is conducted with extraordinary care, the removal of the foreign matter is no doubt better performed than in the example just given. Thus, a sample of Low Moor cold-blast pig-iron, used for the celebrated bars made there, was ascertained to contain—

Silicon, 1·380 per cent. Sulphur, 0·075 per cent. Phosphorus, 0·620 per cent.

This expensive metal is refined and then puddled in small heats. After being flattened under the hammer, it is broken so as to select the best of the iron, which is then piled; and after one, and often more, heatings, it is drawn into a billet or slab, from which the finished iron is rolled. It is only right to say that unrefined Middlesbrough pig when puddled in a revolving furnace gives also a very pure iron. The percentage of the three metalloids in these two kinds of iron, and their strength as certified by Mr. Kirkcaldy, were as follows:—

	Silicon. Per cent.	Sulphur. Per cent.	Phosphorus. Per cent.	Breaking Weight. Tons per sq. in.	Extension. Per cent.
Low Moor . .	0·016	0·010	0·067	22·771	29·68
Middlesbrough.	0·012	0·025	0·085	22·227	29·68

There is however an inconvenience connected with the manufacture of malleable iron, comparatively unknown in steel, which occasionally gives much trouble. The cinder or silicate of iron formed during the process sometimes gets sealed up in the iron, and gives rise to the formation of cavities in the manufactured article. The worst case of all is when the cavity, in the case of a boiler-plate, does not manifest itself until it is exposed to the heat of the fire when in use.

So far as the three above-mentioned substances are concerned, the quantity in which they are present cannot be said to constitute the difference between malleable iron and steel; for we have in one specimen of iron more of them, and in two others less, than in the example given of the composition of steel. So far as our knowledge goes at present, both iron and steel would gain by the entire absence of all three.

The substance which really distinguishes steel from iron is carbon; at the same time, as is well known, examples of malleable iron entirely devoid of this element are rarely if ever met with. Thus Bowling and Low Moor and other well known brands of iron, puddled as they are with so much care, rarely contain under a twentieth of one per cent., and frequently much more. In the manufacture of Bessemer steel, it is found advantageous to blow the metal until the bath, so far as the metalloids are concerned, becomes malleable iron. This may be seen from an analysis in a case where the pig iron used was that made on the West Coast of England. The blown iron contained—

Carbon, 0·10; Silicon, 0·03; Sulphur, 0·04; Phosphorus, 0·06.
Total, 0·23 per cent.

Now there is evidently nothing, so far as relates to these four substances, to lead us to infer that this malleable iron—for such in point of composition it really is—would not possess all the

qualities which render this metal so useful in the arts. As is well known however, this is far from being the case; and to render the blown iron sufficiently malleable to resist the tearing action of rolling, manganiferous pig iron requires to be added.

Recent investigations have led chemists to ascribe the want of malleability in heated iron—or red-shortness, as it is termed—among other causes to the presence of oxygen gas in some form or other. Three specimens made at the Monkbridge Works, one of them red-short, were recently sent to me for examination; and their composition entirely confirmed the soundness of this opinion. On analysis, the two samples which were free from this defect contained only 0·750 and 0·704 per cent. respectively of oxygen, while the one complained of gave 1·384 per cent.

The addition of a substance containing a readily oxidisable metal, such as spiegel-iron or ferro-manganese, carries off this superabundant oxygen, at the same time that it restores sufficient carbon to give us steel of any desired degree of hardness or softness, down to what in the matter of carbon must be regarded as malleable iron.

We have now to choose between what chemically may be considered as the same substance, but made in two different ways—in the one case obtained by means of the puddling furnace, and in the other by the use of the converter.

By the former method we produce a metal interspersed with cinder, which gives rise to unsoundness, or, when exposed to great wear, causes lamination, so familiar to every one in the case of iron rails. By the latter we have a metal free from both these defects, and to which carbon enough can be readily united to form a true steel, capable of enduring twice the tensile strain of the best iron, and, under the same wear and tear, lasting twice as long as an iron rail.

The superiority of quality in the product does not by any means exhaust the advantages possessed by what is often known as the pneumatic over the puddling process. Dissimilar as the two modes of procedure are in appearance, there is in principle not much difference between the two systems. In the puddling furnace the

workman, by very severe labour, exposes the liquid iron to the joint oxidising influence of the bath of cinder and of the atmospheric air. The combustion of the metalloids under such conditions is so slow, and the radiation and other cooling influences, being extended over a much longer time, are so great, that 20 cwts. of coal are consumed for each ton of puddled iron made. In the Bessemer converter, on the contrary, the mechanical action of the workman is replaced by the passage of the air up and through the molten mass of pig iron. By this mode of treatment fresh surfaces of metal are brought so rapidly into contact with renewed supplies of oxygen, that the operation is completed on 8 or 10 tons in one-sixth of the time required in puddling 4 or 5 cwts. Very little heat is wasted in the manner so conspicuous in the puddling process; so that the great heat evolved by the combustion of the metalloids, along with that contained in the pig iron as it comes direct from the blast furnace, suffices for the operation. Thus the only fuel consumed is that required for the blowing engine; and the expense of labour is so much reduced in amount, that the ton of ingots ready for the mill, including the manganese, costs about fifteen shillings less than the same weight of puddled bar made from the same quality of pig iron as that used in the Bessemer converter.

It is now twenty-eight years since this pneumatic process was described by its distinguished inventor; and, with the manifest advantages just referred to in economy of production and in the nature of the product, it may appear surprising that so much puddled iron still continues to be manufactured. This delay in the substitution of a cheaper and better article for one both dearer in price and inferior in quality is due to a variety of causes, some real and others more or less of an imaginary character. First and foremost, it was, as might be expected, many years before an entirely new branch of industry was able to compete in economy of production with a process which was invented by Henry Cort now exactly one hundred years ago. Immediately this point was approached, the greater durability of the new material for rails having in the meantime been demonstrated, railway companies rapidly abandoned the use of iron rails and had recourse to steel. About the period at which we have now arrived in

this brief history of the trade, the great superiority of iron over wood as a material for shipbuilding—which, by the way, it took about a quarter of a century to prove—became generally accepted; so that, as the consumption of iron for railway purposes diminished, that for naval construction took its place. It may well be asked how long, in a structure like a ship, where not only strength but lightness is so important, will the inferior metal continue to be preferred to the superior? A partial answer to this question is found in the fact that, for reasons into which space forbids my entering, the cost of rolling steel ingots into plates was for a long time disproportionately high in comparison with that of converting ingots into rails. The effect of this difference was that, while steel rails were selling at as low a price as those of iron, plates of steel were often £6 a ton dearer than those of iron. This difference at the present moment does not exceed 50*s.* or 60*s.*; and, since a steel ship of the same strength as one of iron is much the lighter of the two, naval architecture bids fair to follow, in connection with the occupation of the puddler, the example already afforded by railways.

Again, the introduction of steel into the construction of locomotive engines and the rolling-stock generally of railroads, was very properly a work of time. Fears were expressed and open assertions were made as to changes taking place in the molecular structure of steel exposed to violent concussion, which changes by leading to sudden rupture might be the cause of disastrous consequences. These fears have been shown to be almost, if not entirely, groundless; and the use of the new material, produced either in the Bessemer converter, or in the open hearth designed by our late lamented Past-President Sir William Siemens, is gradually being extended to many purposes, besides those for railways, in which great strength and durability are needed. No doubt, by many workers in iron, strong objections are still entertained to the abandonment of a material to the manipulation of which they have been accustomed all their lives. Nor am I prepared to assert that this is always the result of mere prejudice; for strongly as analyses may point to an *almost* perfect identity in the composition of malleable iron made by the two methods, pneumatic and puddling, we must

bear in mind how very small a difference in the percentage of foreign matter may greatly affect the quality of the iron containing it. It is possible that this may happen in the case of steel, and yet the defect be remedied by a slight modification in the way of dealing with the metal, in the process of fashioning it into the article required. This however will be quite enough to delay its being readily accepted by individual workmen, who, although employing iron in small quantities, consume in the aggregate considerable weights of the metal. This delay will no doubt prolong for a while the existence of the puddling furnace; but as the nicer details of the pneumatic method become better understood by the manufacturer, and the minuter peculiarities of the product more thoroughly known to the smith, the necessity for the violent exertion of the puddler will probably in a great measure, if not totally, come to an end.

Bearing in mind the immense strides which the art of producing iron has made in the last twenty-five years, the consumer may be tempted to enquire as to the prospects of further improvement in the quality of the product, as well as of further reduction in its cost.

As regards the first of these two questions, it may be difficult to predict what can be done by alloying other metals with iron. Something has been tried in this direction; but no marked success, so far as I know, has attended any of the attempts hitherto made. From time to time great hopes—sometimes indeed great achievements—are announced; but there the matter seems to end. On the other hand, past experience as to the effect of the silicon, sulphur, and phosphorus, taken up by the iron during its passage through the blast furnace, does not justify the expectation that any further diminution in the quantity of any of these substances, below the percentage already attained, can very materially add to its strength; while we know that an addition of any of them has a contrary effect.

A word or two on the second question:—namely, the likelihood of realising any greater economy than that attending the joint action of the blast furnace and the converter.

In proceeding to consider this branch of the subject, we may eliminate any possible saving to be secured by a cheaper mode of working the minerals: firstly, because it is not probable that any *great* reduction of expense can be effected in quarrying limestone or in mining coal or ore; and secondly, because under any circumstances it is only from diminution in the quantity employed of these materials that economy can be hoped for, the saving in mining being common to all processes.

At first sight undoubtedly the blast furnace presents an objection, which however, in my opinion, has had undue weight attached to it. Not only is it alleged that we obtain a product contaminated by substances which admittedly injure its quality, but we also unite with it carbon, which, along with the other elements just alluded to, it is the province of the subsequent operation, be it puddling or converting, to remove. To avoid this circuitous mode of operating, the ancient so-called direct process has been revived; and from no one in recent years has the subject received greater or more intelligent attention than it did at the hands of Sir William Siemens.

It would be impossible, upon such an occasion as the present, to describe in detail all the objections to the direct process. In order to obtain a rough bloom, unfit, without a previous heating and hammering or rolling, for the manufacture of a finished bar or plate, more than 25 per cent. of the iron contained in the ore is oxidised. The blast furnace, on the contrary, gives practically in the pig all the metal of the mineral operated on. It is true a portion of the iron is wasted during the process of conversion; but the waste thus incurred is less than one-third of that which happens in the most successful direct process I have heard of. In the item of labour, I am satisfied, by comparing it with cognate operations, that the united wages paid at the blast furnace and the Bessemer converter are considerably less than what would be expended over the direct process alone. If to the expense of obtaining the rough bloom has to be added either that of a second heating and hammering or rolling, or else that of fusion in an open-hearth furnace, the possibility of competing with the combined action of the blast furnace and converter is *pro tanto* diminished.

In reference to the operations connected with the smelting process itself, there is no branch of the manufacture of iron in which, during the last fifty years, such great amelioration has been accomplished. By means of excellent machinery, by heating the blast as high as it will probably be found practicable or advantageous to raise it, and by a great increase in the dimensions of the furnace, I am tempted to say that we have arrived at a point when further improvement of any moment can scarcely be hoped for. We waste none of the iron contained in the ore; no more limestone is employed than that found necessary to remove the sulphur and to flux the earthy constituents of the minerals employed; and the fuel employed is not one quarter of what Neilson declared it was in Scotland when he discovered the value of the hot blast. That inventor contented himself with blowing in air having a temperature of 500° or 600° F. It is frequently used now at 1400°, and we have been urged to heat it still higher; but, for reasons I have given on former occasions, and which I cannot repeat here, I greatly question whether any large benefit would be derived from an increase, which moreover it would be found difficult to maintain steadily. The only other item in the cost of smelting iron is the labour; and this, by proper appliances and mechanical arrangements, has been so reduced in amount, that I have estimated that each ton of matter, including water and air, handled during the operation, in a properly appointed work, costs not more than $1\frac{3}{4}d.$ for labour.

In reading the addresses of your former Presidents, I observed that upon some occasions advice for future conduct has been added to an examination of the benefits conferred on mankind by the mechanical engineers of this and other countries. Nothing can be more appropriate, either to the individual or to the nation, than a periodical stock-taking, as it were, of the progress which has been made at home and abroad. With this view, no doubt, Mr. Cowper pointed out from the chair in 1880 how the British had been outstripped in the manufacture of certain objects; and reminded you that, forgetful of how much had been achieved by previous exertions, England was failing in the enterprise and energy necessary to keep her in advance of all other nations in arts and manufactures.

That the British people for many years occupied the distinguished position Mr. Cowper is so naturally anxious for them to retain will not, I dare say, be denied by any of our honourable rivals in the industrial race in which some half-dozen nations are engaged with ourselves. In such comparisons as that drawn by my predecessor we must not overlook the vast differences in the circumstances of the two periods he contrasts with each other. Industrial science, as we now understand it, dates from the commencement of the present century: in point of fact, from Watt's grand invention of the steam-engine, properly so called.

Denser population, comparative immunity from the social disturbances attending the wars which unhappily marked the end of the last and the beginning of the present century, extended commerce favoured by our insular position, and the possession of well-explored coalfields, conferred upon the United Kingdom advantages not enjoyed by other European nations.

Recent years have greatly changed the aspect of affairs both at home and abroad. Want of space and of employment has perhaps promoted emigration from our shores to a greater extent than from those of other countries; and, in consequence, the increase of population on the Continent may relatively have exceeded our own. For seventy years, with few and short exceptions, peace has been maintained in Europe; railways have brought inland provinces nearer the coast, and large Continental coalfields have been discovered and developed. With our example before them, it would, under these circumstances, have been a matter of astonishment if other nations had not followed our lead; and with populations, many of them, to say the least of it, as well educated as our own, and gifted with an intelligence certainly not inferior to that of the inhabitants of Great Britain, can it be wondered at that some of the victories in industrial supremacy should have been achieved outside the boundaries of these islands?

The services however, which our own country has rendered to every branch of industry, scientific as well as practical, have been generously acknowledged by other nations. We on our side can well afford to recognise and feel grateful for the numerous and

important contributions to the world's advancement and happiness made by foreign enterprise, in the United States as well as in Europe.

Upon more occasions than one, not only in the addresses which have been delivered by some of your Past-Presidents, but in the public press, the iron trade of Great Britain has been reminded of the competition offered by other nations in neutral markets, as well as in certain articles required for consumption in the United Kingdom. Intimations also have not been wanting that this was a consequence of superior skill exercised, by Germany and Belgium in particular, in arts where hitherto our own country had rendered no mean service.

After what I have just said in reference to foreign competition, I am not going to permit my patriotism to submit any statement of the relative importance of what has been done here and elsewhere towards raising the manufacture of iron and steel to its present high state of excellence. This would be best ascertained by individual research, or by an appeal to those foreign competitors by whom the very existence of the British iron manufacture, according to some authorities, is threatened.

A few years ago an answer to such an enquiry, so far as Germany is concerned, was given by the iron manufacturers of that country; for at that time, in consequence of evidence tendered before a Government commission, a duty was levied of 10*s.* per ton on pig iron and 25*s.* on steel rails imported into the Zollverein, in order to rescue the German iron trade from the absolute ruin which importations from Great Britain were alleged to be sure to effect.

Notwithstanding these representations, these same ironmasters, then making much of their pig iron from the same Spanish ore as that used in England or Wales, with much higher transport charges to pay, were found underselling us in considerable orders for steel rails. The supposed answer to this apparent anomaly was that, protected by the cost for carriage from this country in addition to the heavy import duty, a sufficiently profitable trade in rails for home consumption could be carried on by the German ironmasters, to support a considerable loss on any foreign transaction entered into

after meeting their home demand—a loss which they preferred to that accruing from a partial stoppage of their works.

Since the period in question, the introduction of the basic process has materially improved the relative position of the German steel-rail makers. Pig iron suitable for the acid process, as it is now termed, cost in Westphalia about 20*s.* per ton * more than the phosphoric metal obtained from the liassic ironstone now so largely worked in Germany and in France. In Great Britain, the difference between the two kinds of iron was only about one-third of this amount. If, for the purpose of illustration, we assume 10*s.* to be the additional cost of conversion entailed by the basic process, a Middlesbrough steel-rail manufacturer is left pretty much in the same position as he occupied under the acid system, while his German competitor has gained an advantage of about 10*s.* per ton by the change.

Omitting the actual cost of working the minerals, as this may be greatly affected by the nature of the veins or beds in which they occur, there are two circumstances which operate, generally speaking, in favour of the foreign manufacturer—namely, the price of labour, and the dues paid to the owner of the soil for permission to work coal, ore, and limestone.

With regard to dues, the lowest amount chargeable as royalty against a ton of steel rails in Great Britain may be taken at 5*s.*, whereas in Germany and France it is under 1*s.*, and in Belgium it varies from 1*s.* 6*d.* to 6*s.* On the other hand, the cost of conveying the raw materials to the point where they are manufactured is, generally speaking, less heavy in Great Britain than it is in any of the three Continental countries referred to.

With the cost of labour and of royalty dues operating adversely to the manufacturer in our own country, and the cost of carriage on the minerals in his favour, the balance of the advantages is such that in many smelting works in Germany, France, and Luxemburg, pig iron fit for making malleable iron or steel rails by the basic process can be produced somewhat cheaper, certainly quite as cheaply as a similar quality of iron can be produced at Middlesbrough.

* This difference is given on the authority of Ritter von Tunner.

The point at which we have now arrived in considering the question before us is, whether there is any difference of skill evinced in dealing with the minerals in the blast furnace, and in converting the pig iron thus obtained into rails or other objects, in which the Continental manufacturers are competing with us, not only in neutral markets, but in certain articles of rolled steel and iron for consumption on British soil.

Superiority of skill in the manufacture of iron means less waste of metal, a smaller consumption of fuel, and arrangements of such a character that the same amount of work is done with less expenditure of labour. Measured by these three standards, which are easily investigated, I have arrived at the conclusion, after several years of careful examination in almost every country where iron is made, that if the manufacturers of this kingdom are not in advance of their foreign competitors, most assuredly they are not behind them.

There is a fourth and not an unimportant question, namely the quality of the product. This, as all iron manufacturers well know, is dependent partly on the quality of the raw materials employed, and partly on the amount of labour usefully expended on their manufacture. To this enquiry my answer, *ceteris paribus*, would be in the precise terms employed in the previous paragraph. Give the workmen, be they English, Belgian, French, or German, pig iron and coal of the same description, and give all equally good machinery for dealing with the materials; ask then the consumer to pay for the manufactured article a price corresponding with the pains taken in producing it: and I believe that he will receive for his money the object he requires of equal quality, in whichever of the four countries it may have been made.

I have spoken of the expenditure of labour in the sense of its amount; let us consider it shortly in the sense of its price. This term, of course, is by no means confined to the daily earnings of the individual. Were British miners and iron-workers to be measured by this standard, British iron would speedily be superseded by that of foreign manufacture; because in many departments the workmen

with us are paid 20 to 40 per cent. higher wages than are given on the Continent of Europe. Dearer labour has, no doubt, led to the adoption of means for its economy in our own country; but it is, I believe, universally admitted abroad, that our more highly paid and therefore better fed men are capable of performing, and in most instances do actually perform, more work than is done by the workmen of almost any other nation. This, as regards ironworks, is certainly my own opinion, founded on the number of men required for the same amount of duty in each case. Notwithstanding this greater efficiency of our own labouring population, the wages they are paid exceed the comparative amount of work performed to such an extent, that in many instances its average cost cannot be taken at less than 25 per cent. higher than with Continental nations.

It would not be an easy matter to speak precisely with regard to the average intrinsic value of mining labour. It affects the cost of pig iron, owing to the great variety of the conditions under which it is applied to seams and veins essentially different in their nature. Suffice it to say that there are certain of the best situated places in which, according to my calculations, pig iron, fit for forge purposes or for the basic process of making steel, can be made something like 2 or 3 per cent. cheaper than the same iron in the Middlesbrough district. Such a difference would, of course, be insufficient to cover transport from inland works abroad to sea-going vessels, and freight to this country. We may therefore safely assume that no nation can enter into competition with the Middlesbrough furnaces so far as our own domestic consumption is concerned. The same observation is applicable to steel rails of any ordinary sections, when sold, as they have been of late, at £4 12*s.* 6*d.* or £4 15*s.* per ton. When however we have to deal with tram-rails, or iron and steel in any form worth £8 or more per ton, the extra cost being largely made up of labour, the Continental advantage of 25 per cent. begins to tell heavily against our own manufacturers. This view is being daily confirmed by actual experience; for steel tram-rails, iron girders, together with spring steel, and axles and tyres also of steel, are being imported by some of our large railway companies and house-builders. The change of circumstances in

connection with the basic process above referred to will also, I think, enable the German manufacturer, even in rails of ordinary sections, to compete with us on something like equal terms in markets to which the cost of sea-freight is the same from both countries.

In the North of England we hear of what are now generally known under the name of labour difficulties, more in connection with iron shipbuilding than in almost any other branch of manufactures. In the year 1880 I received from two large establishments a statement of the average earnings for that year. The chief men worked 313 days, during which they were paid rates varying from 8*s.* 9*d.* to 12*s.* 10½*d.* per day. So far as the information I have been able to collect enables me to form an opinion, the workmen in the English ship-yards, all told, receive about double the wages paid abroad; but it would appear that for this extra pay they perform, as has been mentioned in connection with the men in the ironworks, more duty. As with the ironworkers, the extra work however is considerably less than the equivalent of the extra pay, according to foreign rates of wages.

Favoured by the differences in the price of labour, there has recently been established in Norway a shipbuilding yard, where vessels, as well as the steam-engines they require, are constructed out of iron supplied from the north-eastern ports of England. That establishment, begun only a year or two ago, now employs 800 hands. Mr. Raylton Dixon, whose practical knowledge of the trade is so well known, informs me that the actual cost of labour for a given amount of work in the locality in question is 25 per cent. less than he pays at Middlesbrough. This, after paying 10*s.* per ton on the plates for freight from England to Norway, enables the Norwegian builder to construct the hull of the vessel for 15*s.* less per ton of iron employed than is paid in England—an amount equal on a ship of 1500 tons dead-weight capacity to £525. Adding the saving in the wages paid to the carpenters &c., the difference against our own country is brought up to £850.

It is self-evident that, if such a margin as that just named has to continue, we must prepare ourselves for seeing a great increase

in the number of vessels built by means of foreign labour, even if they are afterwards navigated under the British flag. It is moreover not improbable that the plates used in their construction may be brought from German or Belgian ironworks; and this is inferred from the same reason which enables the ironmasters of those two countries to furnish our engineers and architects with railway material and iron girders—namely cheaper labour.

From various sources I have computed that the skilled workmen engaged in the manufacture of ship plates in England earn on an average between three and four times as much as the same class of men do in Germany. According to the last return in my possession, the daily wages in a large plate-mill in the county of Durham were as follows :—

Head shinglers	22*s*. 9*d*.
Puddle rollers	15*s*. 1*d*.
Furnacemen	16*s*. 1*d*.
Head plate-rollers	41*s*. 1*d*.
Head shearmen	34*s*. 9*d*.

Notwithstanding these high rates, it is a remarkable fact that at the *present moment*, owing to the large production, the wages per ton in the finishing mill alone are not higher in the English than in the German work with which it is compared. As soon however as the foreign houses commence to roll plates on the large scale which obtains in this country, there will be a considerable reduction in the cost of production with the former. It may therefore come to pass that the Norwegian shipbuilding may go on increasing, but that the consumption of English iron in connection therewith may proceed in an opposite direction.

I have been induced to give a certain amount of prominence upon the present occasion to the labour question, after reading the observations of Mr. Thomas Hawksley, one of your former Presidents, who has himself had abundant opportunity in his lengthened experience of studying the question in all its aspects. Mr. Hawksley, in his address delivered seven years ago, agrees as a general proposition with what has just been said on the higher cost of British labour. I have endeavoured to show specifically to what

extent the manufacture of iron and the building of iron ships are affected by the condition of things referred to by my predecessor.

To avoid the "ruinous disadvantage when the English capitalist employer is brought by the exigencies of his business into immediate competition with the foreign capitalist employer," the English workman is cautioned by Mr. Hawksley against falling into the error "that he is entitled to share in his employer's success."

It will be observed that this advice is in direct opposition to the course of conduct adopted by the coal-owners and iron-masters of the North of England, who have agreed with their workmen on a scale of wages regulated by the ascertained selling price of their produce. This agreement cannot be accepted as a proof of the soundness of the plan itself; nor of the unsoundness of the doctrine quoted above, and laid down for the acceptance of the men. As a fact however, and it is difficult to see how it could be otherwise, a sliding scale has for many years past been more or less in force in the Northern Counties, as well as elsewhere; because, when trade was active and prices high, labour was in demand, and it, like any other commodity, rose in price. Instead of the purchaser and seller of this commodity having to meet and make a fresh bargain at every fluctuation in price—which entailed delay and frequently interruption to work, under the form of strikes—a self-adjusting scale has been adopted.

Speaking from some lengthened experience with the system, it appears to me, and, I think, to many of my colleagues in these two industries, that its introduction has been satisfactory to both sides. It may and will happen that differences of opinion arise between the two parties on the nature of the scale to be adopted; but these differences are more likely to be reconciled when discussed from time to time with forbearance and good temper by those concerned, probably chosen for their presumed fitness for the office.

It is however of the utmost importance that the whole industrial community should be able thoroughly to appreciate the circumstances by which they are surrounded. The employer is speedily warned of his position; for if he falls behind in the matters of price or of quality, his goods remain unsold if too dear, or if inferior in quality

they decline in value; but this does not apply equally to the workman.

In the markets of the world, the capitalist has to meet competition from whatever quarter it may proceed; and legislation, introduced forty years ago, and in the introduction of which the employers of this country took a conspicuous part, opened the markets at their own doors to the manufacturers of every nation. This same legislation however let in cheap food, and has so equalised the price of all the necessaries of life, that the British workman is able to live as cheaply as his Continental competitor, and to hold his own against all comers in economy of production, as he has hitherto done in the quality of the product of his hands.

Before concluding my remarks I wish to call to your attention the enormous extent of ground covered directly and indirectly by the work of the mechanical engineers in this country. No estimate of this kind can pretend to be more than the roughest approximation; and perhaps the quantity of coal burnt in various processes and manufactures may serve as well as any other measure for the object in question.

About twenty years ago an attempt was made in a government enquiry to assign to the various sources of consumption their proportion of the coal raised. In the first column of figures in the following Table, these proportions are set against each branch of trade. The second column has these numbers applied to the coal wrought in 1882, being the last return issued by H.M. Inspectors of Mines. The quantities thus obtained are then divided in a somewhat arbitrary way. In some of the items, such as railways, the whole quantity may be set down as being employed for mechanical power; while in some of the others the coal is used partly for the development of power and partly for processes in which heat is required as an agent. Such an example is found in the coal consumed in the manufacture of textile fabrics; but even here it is no exaggeration to say that, but for the spinning and weaving machinery, in fact, but for the work of the mechanical engineer, the manufacture of textile fabrics as well as many others would have occupied a very

insignificant position in the industries of the world. I have however, in the rough way already intimated, divided the whole quantity of coal raised under two columns headed M and H (mechanical power and heating): the one headed H containing the quantities more or less independent of any influence exercised by the use of machinery; and the other headed M those affected, directly or indirectly, by the use of mechanical appliances. Iron and steel making is here considered as directly influenced by the use of machinery.

TABLE SHOWING THE PURPOSES TO WHICH THE COAL RAISED IN GREAT BRITAIN IN THE YEAR 1882 WAS APPLIED.

Heads of Consumption.	Out of 1000 tons raised there was used	Total Coal worked, and used as below.	Rate of Division. Per cent.		Mechanical Power. M.	Heating. H.
		Tons.	M.	H.	Tons.	Tons.
Paper-making and Tanning .	6	939,000	50	50	469,500	469,500
Smelting Copper, Lead, Tin, and Zinc	8	1,252,000	10	90	125,200	1,126,800
Water Works	14	2,191,000	100	—	2,191,000	—
Breweries and Distilleries .	18	2,817,000	10	90	281,700	2,535,300
Chemical Manufactories . .	19	2,973,000	10	90	297,300	2,675,700
Railways	20	3,130,000	100	—	3,130,000	—
Steam Navigation	30	4,695,000	100	—	4,695,000	—
Clay, Glass, and Lime Kilns .	31	4,851,500	10	90	485,150	4,366,350
Textile Fabrics	42	6,573,000	60	40	3,943,800	2,629,200
Gas Works	60	9,390,000	—	100	—	9,390,000
Mining Operations	67	10,485,500	100	—	10,485,500	—
Coal Exported	92	14,398,000	50	50	7,199,000	7,199,000
Steam Engines	121	18,936,000	100	—	18,936,000	—
Domestic Use	172	26,918,000	—	100	—	26,918,000
Iron and Steel Works . . .	300	46,950,000	100	—	46,950,000	—
	1000	156,499,000			99,189,150	57,309,850

By this mode of computation it would appear that there is consumed for mechanical purposes, or for industries which are almost wholly dependent on machinery, about 63 per cent. of all the coal raised in Great Britain. The account is no doubt susceptible of considerable modifications in either direction; but one fact will, I think, remain undisputed, namely that a very large proportion of our fuel is applied for purposes directly connected with the profession of the mechanical engineer.

With so large an amount of work to undertake, it is not surprising that, for purposes of mutual instruction, the creation of so important a body as the Institution of Mechanical Engineers should have been found a necessity, or that so great an amount of success should have resulted from its deliberations. For once your President, without the risk of being misunderstood, may congratulate the younger members of this body on having an opportunity afforded to them of listening to the counsel of the most distinguished and the most experienced men, in a profession so largely dependent on experience for the full measure of its success.

The Mayor of Cardiff, in proposing a vote of thanks to the President for his address, said that, although he was himself ignorant of mechanical engineering, he was sure no one could fail to be struck with the great ability displayed in the lucid address to which they had just listened. It would however be impossible even for the Members of the Institution who had heard it, and were so well acquainted with the subject, to estimate at once the full importance of the address, which was one that would bear fruit in future. The President had a world-wide reputation; in South Wales his was a household name; and it was a very fortunate thing for the Institution, and augured well for its future extended usefulness, that gentlemen of such ability and such celebrity as Mr. Bell were found occupying the presidency. He had great pleasure in proposing a vote of thanks to the President for the able address which he had delivered.

Mr. James Colquhoun, President of the South Wales Institute of Engineers, had very great pleasure in seconding the vote of thanks. The encomium passed upon the President by the Mayor was well merited. Many eminent gentlemen had filled the presidential chair of the Institution; but he was sure that the election of Mr. Bell to the honourable position which he now occupied would give additional effect to its usefulness in bringing about the development of science and mechanical appliances. Besides being largely interested in the making of iron and steel, his skill as a chemist, his researches in connection with the blast-furnace and in many things pertaining to metallurgy, had given him a distinguished position not only in this country but in every land where the manufacture of steel and iron was carried on. In the marvellous progress that had been realised in those industries no one had taken a more prominent part; and to him they were indebted for the solution of many practical questions that had all tended to the prosperity of the great industrial enterprises of the country. All present were delighted to see him among them; and he was sure his presidency would prove a great acquisition to the Mechanical Engineers.

Mr. Jeremiah Head, Vice-President, said that as a member of the Institution not residing in South Wales he had much pleasure in supporting the resolution on behalf of the members as well as on his own behalf. When Mr. Bell first accepted under great pressure the office of President of the Institution, with his accustomed modesty he demurred, saying that he did not consider he was a mechanical engineer. He was sure the members would agree with him that, even if Mr. Bell was not technically a mechanical engineer, he had been able to deliver an address so full of matter interesting to mechanical engineers that very few if any of them could have equalled it.

Mr. E. Hamer Carbutt, M.P., said that, as the visit of the Institution was to South Wales and Monmouthshire, he might be permitted, as one of the members for Monmouthshire, to supplement

the remarks that had been made with reference to the President's address, which they all so fully appreciated. He was very glad the President had gone into the labour question, and that he had arrived at the conclusion that, notwithstanding the fact that British workmen were earning 25 per cent. higher wages than foreign workmen, they were able by their skill and ability to maintain their position in the country. What he gathered from Mr. Bell's remark was this: that the great thing they had to look to was to bring science to their aid, and that they should take every opportunity of educating not only the masters and the foremen, but also the men themselves, so that any latent ability which the latter might possess might be utilised to the advantage of the country in its contest with the world. Government had realised this position, and had lately appointed a Royal Commission to enquire into the question of technical education. That Commission, after a labour extending over two years—labour which was entirely gratuitous, for not a single member was paid a penny towards his expenses—had presented a most valuable report, which he strongly recommended to the attention of the younger members of the Institution. Her Majesty had seen fit to confer the honour of a baronetcy upon the chairman of that committee, Mr. (now Sir Bernhard) Samuelson, for many years past a member of this Institution: which might therefore be regarded as an honour to the Institution as well as to himself. He hoped that after the leading position which the President had taken in the iron trade, after a life devoted to scientific questions connected with the production of iron, it would not be long before Her Majesty would see fit to confer upon him the like honour, of which he believed, having known the President personally for many years, there was no man more worthy; and from the applause with which this suggestion was now greeted he was satisfied that the members of the Institution shared his belief.

The vote of thanks to the President for his Address was passed unanimously.

The PRESIDENT said he was unable to give adequate expression to his high appreciation of the remarks which had fallen from his four friends, and of the kind concurrence of the members. Willing as he was to be convinced by anything that Mr. Head might say, his own opinion had not been altered with reference to his fitness to fill the position which he occupied; and he had no doubt many more capable men as mechanical engineers might have been selected for the office of President of the Institution. But the matter had been so pressed upon him that he had consented to occupy the chair; and if his future endeavours to promote the welfare of the Institution were as successful as their kind appreciation of his remarks led him to hope they might be, he should be abundantly satisfied. He had accepted the position because, unfortunately for himself, he was no longer as young as many of those whom he had the pleasure of seeing around him; and it had occurred to him that possibly, after having spent a long and active life in observing matters of great interest to himself, the results of those observations might be of some use to those with whom he had worked so long and with so much pleasure. He hoped the remarks which he had made on the labour question would not be misunderstood by those to whom they were in reality more particularly addressed,—namely the workmen themselves. He had never had any wish to interfere with the proper reward to which labour was entitled, everything considered. But he did think it was very important indeed that the labouring population of the country, as well as their employers, should be made acquainted as far as possible with the actual circumstances of the case; and in that spirit alone had he ventured to address to them the few remarks which had been so favourably received by the members.

ON RECENT EXTENSIONS OF DOCK ACCOMMODATION AND COAL-SHIPPING MACHINERY AT THE BUTE DOCKS, CARDIFF.

By Mr. JOHN McCONNOCHIE, of Cardiff.

On the occasion of the former Summer Meeting of the Institution held in Cardiff in 1874, the author had the pleasure of giving a paper on the Bute Docks and the Mechanical Appliances for Shipping Coal, in which he described the origin, growth, and existing extent of the dock accommodation at Cardiff, the balance tips and hydraulic tips and anti-breakage cranes in use for the shipping of coal, with the hydraulic hauling engine and portable hydraulic crane, and also the motive power for working the hydraulic machinery (see Proceedings 1874, page 119). These various appliances were severally shown in the engravings accompanying the former paper. Without repeating therefore the particulars then given, the object of the present paper is to describe briefly the further progress and improvements that have been effected during the ten years which have elapsed since that time. A general plan of the whole of the docks is given in Fig. 1, Plate 28.

Roath Dock.—In 1882 an act was obtained for the new Roath Dock now in course of construction, Plate 28, which is to be entered from the Roath Basin through a lock 600 ft. long by 80 ft. wide, with three pairs of wrought-iron gates, similar to the gates in the sea lock of the Roath Basin, described in the former paper. The gates are being constructed by Sir William G. Armstrong, Mitchell and Co.

The dock is to be 2400 ft. long by 600 ft. wide, having an area of 33 acres. The depth from coping to sill is 43 ft. 6 ins., and the bottom of the dock is 3 ft. below the sill level. The depth of water on the sill at high water is 35 ft. 8 ins. at ordinary spring tides, and

10 ft. less at ordinary neap tides. The construction of this dock was formally inaugurated by the Marquess of Bute on the 30th January 1882, and the work is to be completed in October 1885, the contractors being Messrs. Nelson and Co. of Carlisle. It is intended to devote the whole of the north side and east end of the dock to the shipment of coal, and the south side to the import and export trade of timber, iron, iron ore, and general merchandise. On the north side will be erected appliances of the most approved kind for the shipment of coal.

Coal-Shipping Machinery.—The first hydraulic machines at Cardiff for tipping coal direct from trucks into the vessels were four put up for the Great Western Railway as far back as 1857 by Sir William G. Armstrong and Co. They were fixed hoists, differing but little from those now in use, except that in two of them the lift was only 15 ft. and in the other two 22 ft. The increasing size of vessels has necessitated a corresponding increase in the height of lift of the coal hoists; and the last two hoists erected at Cardiff in 1880 have a range of 27 ft. These, curiously enough, were for the Great Western Railway, to replace the two with 15-ft. lift erected in 1857, which were found to have too short a lift. They are on the east side of the Bute East Dock.

Since 1874 the additional machinery for shipping coal is as follows:—

a. One hydraulic tip has been erected on the west side of the East Dock by Messrs. Brown Brothers and Co. of Edinburgh.

b. Tips Nos. 1 and 3 on the west side of the East Dock have been converted from balance to hydraulic tips, the machinery being supplied by Messrs. Parfitt and Jenkins of Cardiff, and erected by the workmen of the Bute Trustees.

c. Two hydraulic tips have been erected on the east bank of the River Taff, which are connected with the Great Western Railway by a branch from the main line near Cardiff station.

d. One movable hydraulic crane, capable of lifting 25 tons, has been erected on the east side of the Roath Basin, between Nos. 1 and 2 tips.

Movable Hydraulic Crane.—The employment of steamers instead of sailing vessels for carrying coal necessitates a much quicker despatch; and the increasing length and number of hatchways in the steamers have for some time made it most desirable to be able to load into two hatchways at least at the same time. With fixed machines this has been found impossible, except in rare cases, because the positions of the hatchways vary so much. It therefore became a question as to the possibility of using movable machines; and it was with a view of practically trying this that the movable crane tip at the Roath Basin has been put up. Fixed cranes have of course been in use for some years at other ports, for shipping coal direct from the truck; but it has hitherto not been practicable to make such cranes movable, owing to the cradle or platform on which the truck is lifted requiring a pit or gap in the line of rails for its reception. This special seating for the cradle rendered it necessary that the crane should always pick up and deposit the wagons at one point. It is obvious that these arbitrary fixed points of picking up and depositing the wagons on the lines are not compatible with movable tips, inasmuch as it is absolutely necessary that the lines of rails should be parallel with the quay, and be continuous without break or gap, so as to be common to the tip in any position in which it may be placed along the dock wall.

The problem has been solved in a very ingenious and efficient manner by Mr. Westmacott's coaling cradle C, Fig. 24, Plate 39, which must be looked upon as the key to the successful application of movable coal-shipping appliances. It may be described as a light platform suspended by chains, which takes its seat on an ordinary line of rails in any position. It is suspended on what may be called an anti-friction swivel S, shown to a larger scale in Figs. 27 and 28, which enables a man to turn the cradle with a loaded wagon on it, thereby dispensing with turntables. There are no tipping chains to hook on and off every time a wagon is shipped, as is the case with coaling cradles of the usual construction; the tipping chains TT in this case pass through the centre of the swivel attachment S, Fig. 28, and are permanently connected with the cradle C.

The crane itself, as shown in Figs. 21 to 24, Plates 38 and 39, consists of a nearly square wrought-iron pedestal or base, tapering upwards, which is carried on four wheels, one near each corner, running on rails of 24 ft. gauge laid parallel to the quay wall. These wheels however are used only for travelling on; the whole of the weight when working is taken by four hydraulic jacks JJ, one at each corner, which effectually prevent any movement of the crane.

Rising out of the top of the pedestal, and revolving in bearings at the top and bottom of it, is the pillar P, Figs. 21 and 22, consisting of two flat plate-girders, between which is placed the hydraulic cylinder for lifting. The lifting chain L from this cylinder passes over the jib head, and both ends are made fast to the swivel attachment S above the cradle. The jib is attached at the lower end to the front of the pillar P, just above the pedestal; and at the outer end by stays to the top of the pillar. On the back of the pillar is fixed a second hydraulic cylinder B, which effects the tipping of the wagon by making a bight in the tipping chain T that passes over the jib head to the cradle. The tipping chain is always kept taut by a third hydraulic cylinder D, placed on an inclined frame which is fixed to the pillar at the back in the same way as the jib is in front; thus the tipping cylinder proper needs to have a short range only, the inclined tightening cylinder D being of course locked by its valves while the tipping cylinder B is in action. The tightening cylinder D and its frame act as a counterweight, for balancing in some measure the load hanging from the jib head.

The turning of the pillar and jib is effected by a pair of horizontal hydraulic cylinders EE, Fig. 22, one on each side of the pillar, and fixed to the base of the pedestal, which itself remains stationary. The chain from these cylinders passes round a drum at the foot of the pillar.

All the motions are controlled with the greatest ease by one man in a valve-house V, Fig. 23, on the side of the pedestal. There are two of these houses on opposite sides of the machine, so that he can use whichever is most convenient for enabling him to see into the vessel. The pressure water is conveyed to the crane by movable and jointed pipes, which can be attached to hydrants placed at convenient distances on the hydraulic mains along the quay wall.

There is an auxiliary or anti-breakage crane on the side next the dock, the foot of the jib A being carried from the pedestal, and the top by means of a chain from the top of the pillar, Figs. 21 and 24, Plates 38 and 39. By an arrangement by Mr. Charles L. Hunter of the Bute Works, of a hopper H resting on the ship's deck, with telescopic throat of square section which is closed by a pyramidal bottom or valve held up by the auxiliary crane A, the first few wagonfuls of coal can be lowered quietly to the bottom of the hold for the following coal to fall on, as is done at the hoists, so as to lessen the breakage of coal, as shown in Figs. 24 to 26, Plate 39. When the anti-breakage crane A is not in use, it can be swung to one side, clear out of the way.

It is found in actual work that a wagonful can be shipped in from $2\frac{1}{2}$ to 3 minutes. The crane was designed and constructed by Sir Wm. G. Armstrong, Mitchell and Co., and is similar to their well known and largely adopted movable hydraulic cranes for cargo and ballast work. These cranes were first introduced at the suggestion of the writer about fourteen years ago at the Atlantic Wharf of the Bute East Dock, to supersede fixed cranes. The introduction of the movable crane resulted in such an increased amount of work and despatch to steamers that all the dock companies very soon recognised the importance of adopting cranes of this type. At the Royal Albert Dock, London, there are about ninety of these cranes.

The number of tips for shipping coal at the Bute docks is now as follows:—

13 balance tips at the West Dock } shown at BB in Fig. 1, Plate 28.
12 „ „ at the East Dock }

8 hydraulic tips at the East Dock and entrance basin, shown at HH.
1 „ „ in the entrance channel for loading in the tideway.
8 „ „ at the Roath Basin.

—

42 total number of tips.

—

1 movable hydraulic crane capable of lifting 25 tons.

2 A 2

Each tip is capable of shipping 1000 tons of coal per working day; the total shipping capacity of the Bute docks is therefore equal to nearly 12 million tons of coal per annum. In some instances as much as 200 tons of coal have been shipped per hour at the hydraulic tips; and it is now not uncommon for a steam collier of 2000 tons burthen to enter the basin at high water of one day, discharge her ballast, receive her outward cargo, and leave at high water the following day, the entire operation having occupied less than 24 hours.

The principal portion of the trade carried on in the Bute docks is the export of coal and iron, which amounted to $2\frac{3}{4}$ million tons in the year 1873, and to 6,916,000 tons in 1883. The import trade of iron ore, timber, and general merchandise, amounted to 630,000 tons in 1873, and in 1883 to 1,299,000 tons.

Railways.—The mineral traffic of the West Dock is supplied exclusively by the Taff Vale Railway from Merthyr, Dowlais, and the Aberdare and Rhondda Valleys. The traffic to the East Dock is supplied jointly by the Taff Vale, the Rhymney, and the Great Western Railway: the last of which is the means of communication with the great coalfield now being opened in the centre of Glamorganshire in the Ogmore district. The London & North Western and the Midland Railway have also access to the docks by their connection with the above railways.

Sidings.—A very large extent of siding accommodation is required for working the coal-shipping trade; for, owing to the fluctuations of the trade, loaded wagons have to be stored in the sidings at times when the supply exceeds the demand. The extent of main lines and sidings provided and maintained by the Bute Trustees in connection with the docks amounts to 70 miles in length: namely 25 miles of main line and 45 miles of sidings, the whole of which is fully occupied. In addition to this the Taff Vale Railway has constructed a large system of sidings 7 miles in length, above Crockherbtown Junction.

Graving Docks.—The provision for the examination and repair of vessels entering the port consists of eight graving docks.

1. *Public Graving Dock.* — The commercial graving dock, constructed by the Bute Trustees, is available for use by the public on payment of dockage rates as at Liverpool. This graving dock R, Plate 28, shown in plan and transverse section in Plate 29, is 600 ft. long, 78 ft. wide at the coping and 56 ft. at the bottom, with an entrance 60 ft. wide from the Roath Basin, the depth of water on the sill at high water of ordinary spring tides being 23 ft. 9 ins. The bottom of the graving dock is 2 ft. 6 ins. below the sill, and is laid with a line of cast-iron blocks 4 ft. apart throughout its entire length, the upper edge of these blocks being on the level of the sill. Access to the dock is gained by the steps at SS, Fig. 2, Plate 29, in which also are slides for passing down materials required for the repair of vessels.

Caisson.—The entrance is fitted with a wrought-iron boat-shaped caisson, shown in Figs. 4 to 8, Plates 30 to 32. It is 60 ft. long, 26 ft. in greatest width and 13 ft. in least width at the centre, and 30 ft. 6 ins. in depth; and is constructed of angle-iron frames, columns, and beams, and skin plates, with oak keel and stems, Figs. 6 and 9, and fir deck-planking. It is divided at about half its depth by a water-tight deck at Y Y, Plate 30, and below this by bulkheads into sixteen compartments communicating with one another by means of small slide-valves, for water-ballast arrangements. To give the necessary displacement for any required flotation level, the water ballast is admitted into the four central compartments (from which it flows into the others) by two 9-inch cast-iron inlet pipes II, or is discharged through the outlet pipe D, Fig. 8, each of which is fitted with a brass-faced valve worked from the deck. A small steam-pump is fixed on the water-tight deck for the purpose of discharging the water ballast, in case of the depth of water on the sill being reduced whilst the caisson is afloat. The 24-inch cast-iron sluice-pipes PP, fitted with valves worked from the deck, are fixed in the caisson for filling the graving dock. In addition to the water-ballast, there are about

120 tons of iron ballast in the caisson, which, with the weight of the caisson itself, including the cast-iron pipes, pump, &c., amounting to 152 tons, is equal to the displacement at the lowest water-level at which it requires to be floated. The details of this caisson required careful consideration to provide by water ballast for a variation of 13 feet between the high water of high spring tides and the high water of low neap tides; and the author is indebted to the valuable assistance of Sir Edward J. Reed, K.C.B., M.P., in the arrangement of these details.

Pumps.—The pumping machinery for discharging the water from the graving dock is shown in Figs. 10 to 13, Plates 33 and 34. It consists of two centrifugal pumps, Plate 34, each working in a separate circular well, and driven by a high-pressure horizontal engine; and four lift-pumps, Plate 33, all fixed in one square well, and driven by a direct-acting condensing engine. The water from the graving dock flows through a culvert C into the square well, Fig. 2, Plate 29, whence it passes by separate culverts AA into the circular wells, Plate 34; and there is also a culvert D fitted with a sluice L between the two circular wells, Fig. 12. The water from the whole of the pumps flows away through the culverts BB and pipe P, Plates 34 and 33, to a tank or well under the boiler-house floor, from which it is conveyed by a 5 ft. culvert to the East Dock. When the pumps are started, the sluice L between the two circular wells is closed, Fig. 12, and each centrifugal pump acts independently until the water level in the graving dock is so reduced that the lift of the pumps is equal to about 15 ft.; the sluice L is then opened, and the water discharged by the lower pump passes into the other well through the culvert D, below the level of the higher pump. When this takes place, the self-acting inlet flap F (shown in Fig. 12 as partly open) closes, and prevents the return of this water to the dock. The water discharged by the lower pump is thus passed through both pumps, and they divide the lift between them.

Centrifugal Pumps.—The construction of the centrifugal pumps is shown in Figs. 14 and 15, Plate 35. The cover C over the revolving fan F is for the purpose of removing the great pressure of the water from a large part of the upper surface of the fan; and

as the water pressure has access to the underside of the fan, this pressure, instead of increasing the weight on the bearings, tends to support the fan, and relieves the bearings of almost the whole pressure on them due to the weight of the fan and spindle. Although the joint between the cover and the fan is nearly water-tight, it cannot be made perfectly so without too much friction; and the little leakage which takes place is removed to the underside of the pump through the three hollow standards or supports S. The space between the cover and revolving fan is thus always kept free of water pressure; and the fan and spindle bearings are relieved from friction that would otherwise absorb much power in overcoming it. The revolving fans are 4 ft. 2 ins. diameter, and when driven at their usual speed of about 200 revolutions per minute they discharge about 3000 cubic feet of water in that time.

Lift Pumps.—The four lift-pumps, Plate 33, are each $29\frac{1}{2}$ inches diameter, and 48 inches length of stroke. Their general speed is about fourteen strokes per minute, at which rate each pump discharges about 250 cubic feet, equal to 1000 cubic feet discharged per minute by the four pumps together. They deliver into the pair of wooden troughs W, which convey the water into the discharge-pipe P common to all four. The vertical condensing engine which works the lift-pumps works also two force-pumps auxiliary to the force-pumps for the service of the hydraulic machinery. Steam for this engine and for those driving the centrifugal pumps is supplied by three high-pressure boilers, working at 70 to 75 lbs. pressure; and by one low-pressure boiler, working at 10 to 20 lbs. pressure.

A pipe E, with a valve V, in the square well in which the lift-pumps are fixed, Fig. 10, Plate 33, is for the purpose of filling the graving dock from the East Dock when desired. The whole of the pumping machinery has been supplied by Messrs. R. Moreland and Son of London.

2.—The second graving dock is at K, Fig. 1, Plate 28, at the head of the Bute West Dock, and was constructed by Messrs. Charles Hill and Sons; it is 230 ft. long, with an entrance 40 ft. wide, and $12\frac{1}{2}$ ft. depth of water over the sill. Vessels can here be docked at all times, irrespective of tides.

3 *and* 4.—Two graving docks have also been constructed by Hills' Dry Docks and Engineering Co. at the north-west side of the Bute East Dock, at M, Fig. 1, Plate 28. One is 408 ft. in length, with an entrance of 48 ft. width, and 18½ ft. depth of water over the sill. The other is 400 ft. in length, with an entrance of 40 ft. width, and 18½ ft. depth of water over the sill. Vessels can be docked in both docks at all times, irrespective of tides. The docks are pumped out by a pair of centrifugal pumps, with suction and delivery pipes of 18 ins. bore and revolving disc of 4 ft. diameter, made by Messrs. W. H. Allen and Co. of Lambeth. Each pump is intended to discharge 6,000 gallons of water per minute; the two together have discharged on trial 18,000 gallons per minute, emptying the dock then in two hours. Each is driven by its own engine, having inverted cylinder of 15 ins. diameter and 12 ins. stroke, and working at an average speed of 180 revolutions per minute, with 60 lbs. steam cut off at 3-8ths of the stroke. Either engine can work either pump, and can pump out either of the docks. The pumps have to discharge the water from the dry docks into the basin, the maximum height of lift being 22 ft. They are charged by means of a steam ejector, which exhausts the pipes and pumps in about one minute, thereby dispensing with a foot-valve; a self-acting flap-valve on the delivery side is alone required.

5.—One graving dock at D, Fig 1, Plate 28, with an entrance from the basin of Bute East Dock at one end, and another entrance from Bute West Dock at the other end, has been constructed by the Cardiff Junction Dry Dock and Engineering Co. It is 420 ft. in length between the caissons, and 77 ft. in width at top of coping, with 18 ft. depth of water on the blocks, Fig. 16, Plate 36; the entrances are 50 ft. in width, and the depth of water over the sill 20 ft. Vessels can be docked at all times, irrespective of tides; and this dock is available in case of need as an additional entrance to the West Dock through the East basin. The water is let into the dock from both ends, through two sluices SS in each caisson, Fig. 18, Plate 37; and the dock can be filled by these sluices in thirty minutes.

Caissons.—The caissons, Figs. 18 to 20, Plate 37, are fitted in grooves formed in the masonry, and are lowered and held down in their places by water-ballast run in through inlet-valves; the sinking occupies three minutes. For the purpose of raising the caisson, which has to lift about five feet in order to clear the sloping side-grooves, Fig. 18, the water is pumped out by two pulsometers, which are fitted inside the caisson and are supplied with steam from the main boilers, the steam pipes being connected by flexible hose; the time occupied in lifting is six minutes. This dock and caissons were designed by Mr. J. A. McConnochie of London.

Centrifugal Pumps.—The whole of the water from the graving dock is pumped up to a level not less than one foot above the dock coping, and is returned to the Bute Docks. The pumping machinery was designed and constructed by Messrs. Parfitt and Jenkins of Cardiff. There is one pump-well only, Figs. 16 and 17, Plate 36, constructed of stone, and 9 feet diameter. In this well is fitted a vertical shaft, on which are two centrifugal pumps CC, Fig. 17, each precisely the same in design and dimensions. The bottom one is fixed 2 feet below the level LL of the dock bottom, and the upper one 14 feet above the lower, leaving about 14 feet head on the top pump when working full speed. The pumps make 210 revolutions per minute, and are driven by a pair of horizontal compound condensing engines, geared to the pumps by mortice bevel-wheels. The engine cylinders are 22 and 40 inches diameter with 30 inches stroke, making 70 revolutions per minute, or one-third the speed of the pumps; pressure of steam from 65 to 70 lbs. per sq. inch.

Bucket Pumps.—Besides the main centrifugal pumps there are a pair of drain pumps, used for pumping out any leakage from the caissons into the dock. They are a pair of ordinary bucket-pumps, 19 inches diameter and 4 feet stroke, worked direct by a high-pressure beam-engine having a 16-inch cylinder; and the pump rods BB, Fig. 17, are hung off the extended ends of the beam. This engine makes about 16 revolutions per minute, and for pumping out the dock it works in conjunction with the main centrifugal pumps.

The engines are supplied with steam by two boilers of the marine type, having brick flues at the back, instead of the ordinary combustion chambers. The boilers are 10 ft. 3 ins. diameter and 11 ft. 3 ins. long.

The dock when full contains about 16,000 tons of water, and the time occupied in pumping it dry is $2\frac{1}{4}$ hours. When docking an ordinary sized steamer the time occupied is about 2 hours.

6 *and* 7.—Two docks at N, Fig. 1, Plate 28, each entered from the west side of the entrance channel to the Bute Docks, belong to the Mountstuart Shipbuilding Graving Docks and Engineering Co. One dock is 324 ft. in length, with an entrance of 45 ft. width, and depth of high water over sill 19 ft. 9 ins. at ordinary spring tides, and 10 ft. less at ordinary neap tides. The other dock is 420 ft. in length, with an entrance of 52 ft. width, depth of high water over sill 26 ft. at ordinary spring tides, and 10 ft. less at ordinary neap tides.

8.—A graving dock, with an entrance from the Roath Basin, is now being constructed at E, Fig. 1, Plate 28, by the Bute Shipbuilding Engineering and Dry Dock Co. It is 600 ft. long, 87 ft. wide at top, and $28\frac{1}{2}$ ft. deep, with an entrance 55 ft. in width, depth of high water over sill 25 ft. at ordinary spring tides, and 10 ft. less at ordinary neap tides. Most vessels will be able to enter or leave at any time, as the ordinary working level of the Roath Basin gives about 18 ft. of water over the sill. Provision has been made for dividing the dock into two lengths by a caisson, which can be placed in any one of three recesses, either at the middle of the length or at 50 ft. on either side of the middle; the inner division can be used for a vessel requiring to stay a longer time in dock, and the outer for vessels staying a shorter time. The dock may be filled either direct from the tideway or from the Roath Basin. It will be emptied by two centrifugal pumps of 4 ft. diameter, on vertical shafts, each in a separate well. Two horizontal non-condensing engines will be provided, one for each pump, the cylinders being 16 ins. diameter with 3 ft. stroke, to work with 80 lbs. steam. A small separate pump

with engine is also provided for getting rid of any leakage water without running the large pumps. These pumps are designed to empty the dock in about four hours, the quantity of water to be discharged being about 929,000 cubic feet. This dock was designed by Mr. J. A. McConnochie of London.

Gridiron.—On the east side of the entrance channel to the Bute Docks a gridiron G, Fig. 1, Plate 28, has been constructed by the Bute Trustees, of which the length is 350 ft., and the width 36 ft.; the depth of water at high water is 23 ft. at ordinary spring tides, and 13 ft. at ordinary neap tides.

Discussion.

Mr. McConnochie said he should be happy to show the members in the afternoon at the docks everything that had been described in the paper, which would be the best way of enabling them to understand the works in all their details.

Mr. Benjamin Walker thought the most interesting part of this valuable paper was the description of the movable coaling crane made by Sir William G. Armstrong, Mitchell and Co. Up to the present time he had always supposed it was the invention of Mr. Westmacott; but it now appeared from the paper that Mr. McConnochie was the first to suggest its use. It had been extensively applied both in this and in other countries. At the present time his own firm had no less than 122 hydraulic cranes under construction, fifty-six of them being portable and all exactly alike for the Tilbury Dock near London, constructed by the East and West India Dock Company. It was found that the first cost of the crane, including the foundation, was less when made portable than when fixed. The facility of loading by bringing say three cranes to three

(Mr. Benjamin Walker.)
hatchways was enormous; the quantity of goods that could be shipped in the time was more than doubled, and the facilities given to the workmen for superintending the unloading were greatly increased. From the paper itself and the accompanying drawings it appeared there were certain additions to the crane as made by Sir William Armstrong and Co.; and having already been down to the docks and looked at the crane, he thought the attention of the members should be prominently directed to the anti-breakage arrangement for distributing the coal at the bottom of the ship. That arrangement he understood from Mr. McConnochie was due to Mr. Charles L. Hunter, the mechanical engineer of the Bute Docks; it appeared to him to be a most ingenious contrivance, reflecting great credit on Mr. Hunter, and it was a very valuable addition to the crane. Without it, the coal to be shipped and used again would have been very much damaged and lessened in value; but with it the labour of the workmen was very much reduced, and the coal was very easily spread over the bottom of the ship without breaking. He had never seen this contrivance before, and thought it was clearly a new notion, for which due credit ought to be given to the inventor. Notwithstanding the many ingenious contrivances already introduced, he did not think the way was yet blocked for further improvements in the shipping of coal; other contrivances he was sure would before long be found, more adaptable, more easily worked, and involving less cost. It was a satisfaction to know that the field was still open for other and better contrivances for shipping coal. The other parts of the movable hydraulic crane were like the well-known Armstrong crane, of which no one could speak too highly; it was a most excellent piece of work, and substantially constructed.

Mr. Joseph Tomlinson remembered that when he went to Cardiff in 1858 there were only the very limited coal-shipping appliances mentioned in the paper; and it was considered they were doing a very good business when they shipped something like 1½ or 2 million tons a year. The quantity had now got up to 7 millions; and from what the author was now doing, it seemed likely that the 12 millions spoken of in the paper as the present coal-shipping capacity of the

Bute docks would be increased to 15 million tons per annum. The coal of the district being so much in demand, he thought it very probable that the further provision now being made for shipping it would be none too great. Not having seen the docks for some years, he had been greatly struck with the improvements that had taken place. It was only by such devices as were now being adopted that such an extensive trade could by any possibility be carried on. The movable hydraulic crane had been described in the paper as Mr. Westmacott's; and its introduction at the Bute East Dock had been suggested by the author.

Mr. McConnochie said the telescopic shoot for preventing breakage of the coal in shipping was stated in the paper to be the invention of Mr. Hunter; it had been made by him at the Bute Works.

With regard to the movable hydraulic crane, the idea was his own, but not altogether so. It arose in this way. Each tip had a fixed hydraulic crane attached to it, which was called an anti-breakage crane, for lowering the coal down in a bucket to form a conical heap in the ship's hold. Mr. Nixon, one of the large colliery proprietors, was complaining, with regard to some of the vessels sent out to China, of the great proportion of small coal; and asked him if he could not reduce it. He replied that he would try to reduce it by loading a vessel by means of wheelbarrows; this was done by means of a tray that held four ordinary wheelbarrows, which were filled by hand from the railway wagons, using also a shovel with holes in it for the small to fall through, just as it did in passing over the screens in the shoots; the tray was lowered by a crane down into the hold, and the coal was wheeled to the place where it was to be stowed. In this way he loaded three vessels that went to Madeira. When they arrived there, no one would believe they could have come from Cardiff, because in former cargoes there had always been so much small coal. It then struck him that he could do double the work if he had a second crane, which should be a movable one; and he asked Messrs. Armstrong and Co. to make one, but they replied they could not, having often tried but always failed in the pipes. He remembered

(Mr. McConnochie.)
as a boy seeing on the Clyde Nasmyth's pile-driving engine, and it was there that he caught the idea of jointed pipes. When he mentioned this to Messrs. Armstrong and Co., the movable crane was made, and it had since been employed at Cardiff and elsewhere. It was a 25-ton hydraulic crane, and there was nothing new about it except the arrangement for rendering it movable. Fixed hydraulic cranes for shipping coal had been used in Liverpool more than thirty years ago; and the object of the movable crane was to enable them to do double the amount of work they were previously doing. With the addition of the telescopic shoot made by Mr. Hunter, the crane had been very successful. It not only shipped the coal, but also trimmed it to a certain extent, spreading it about the hold.

The PRESIDENT called upon the members to thank Mr. McConnochie for his valuable paper, and for the treat which awaited them of visiting the docks, and seeing all that had been so admirably described.

DESCRIPTION OF THE NEW LOCOMOTIVE RUNNING SHED OF THE TAFF VALE RAILWAY AT CATHAYS, CARDIFF.

By Mr. CHARLES H. RICHES, of Cardiff.

Owing to the large increase during the past few years in the traffic of the Taff Vale Railway, it became necessary to remove the Cardiff Engine Shed from the old site at the Cardiff terminus to a new and more eligible one at Cathays. The arrangements of the new shed, with its adjacent yard and appurtenances, are shown in Figs. 1 and 3, Plates 40 and 41.

Main Shed.—The main shed is built to accommodate sixty large tender-engines, and is 383 feet long inside the walls, Fig. 1, Plate 40. It comprises two spans of 67 feet each, divided by a centre wall, which is supported by elliptic arches, resting upon brick pillars, Fig. 2. There are five roads under each span, making ten in all. Midway in the length of the shed is placed a steam traverser, 40 feet long, which works at the floor level right across both spans of the shed, so as to remove engines from any one of the ten roads. The pits are numbered from No. 1 on the eastern side of the shed, up to No. 10 on the western side. The same numbers hold good for the corresponding lines of road throughout the entire length of the shed, that is to say both north and south of the traverser; and the length of the shed is divided into six divisions or tiers of berths. Commencing from the ten pairs of outlet doors at the north end, the first berth is lettered A: consequently the ten engines against the doors will be in berths 1 A to 10 A. The next tier of berths is

lettered B; and so on to F, the last at the south end, which is invariably used for "day-in" engines. This plan of berthing the engines of each "booked train" enables the men to find their engines at once when they come on duty; and obviates delay, which otherwise would inevitably arise in so large a shed.

Engine Pits.—The main pits are 3 ft. 6 ins. deep, and extend throughout the entire length of the shed, excepting under the traverser. In all the pits there are drains at intervals of 46 ft. 10 ins., each of which is trapped with a syphon box; underneath the box is a sump, 2 ft. square and 3 ft. deep, for the purpose of catching any refuse; and the drain pipes lead away at a height of 2 ft. from the bottom of the sump. In every alternate space between the pits there is a water main, with hydrants at every 37½ ft. These are covered with cast-iron frames, Figs. 5 and 6, Plate 42, having a small lifting flap for the insertion of the stand-pipe, which keeps the hose clear of the floor; and when not in use the whole falls flush with the floor. All the hydrants have screwed plugs, and are of course duplicates of one another. Between all the roads the floor of the shed is pitched with firebrick set on edge. At the berths F at the south end, called the "day-in" tier, Fig. 1, pieces of hard wood are let into the pitching alongside each road, for placing lifting-jacks upon; and along the wall at the south end of the shed, adjoining these berths, are the fitters' benches.

Workshops and Offices.—Across the south end, and covered by continuations of the same roofs, are placed the workshops and offices, Fig. 1, Plate 40. The coppersmiths' shop G, entered through the end wall at the south-west corner, is 19½ ft. wide and 19¼ ft. high to the eaves. Adjoining this comes the smiths' and boiler shop H, also entered from the main shed near the longitudinal centre wall. These two shops together occupy the end of the western span. In the eastern span, and having also an entrance from the shed, comes the machine shop K, in the corner of which is placed the chief foreman's office I; then the passage for the workmen's entrance J, and finally a tier of timekeepers' offices. The southern extension of the main

roof is 30 feet, and consequently all these shops have an equal width, as shown in the plan, Fig. 1. The offices on the eastern side of the entrance passage are two in number: the one L nearest the shed being for the train-booking timekeeper, and the other M for those taking enginemen's "trips" and shedmen's tickets. Adjoining the latter, but covered by a lean-to roof, is a trainmen's waiting-room N, where the men remain to give their "trips" off, and await orders for trains. The lean-to roof extends across the whole south end of the shed; and under it are placed two long mess rooms PP of 30 ft. length and $14\frac{1}{2}$ ft. width, and also the stationary engine and boiler houses RR, Fig. 1.

The lighting of the shed is by gas; but it is intended to light the yard and approaches by electricity.

Drop Pits.—Outside the shed at the northern or outlet end the ten roads lead to separate drop pits, Fig. 1, each of which has a large syphon drain, fitted with similar sumps to those in the shed; and each pit has also a water jet arranged as shown in Figs. 7 to 9, Plate 42, for enabling the men, when dropping fire, to set the nozzle N at any angle, Fig. 9, and throw the water into the ash-pan without the use of flexible hose. Adjoining the drop-pits are erected two double-fire furnaces SS, Fig. 1, for lighting the engines; and there is also a third T by the doors of the traverser. At the further end of the drop pits are five water-cranes, Fig. 1, placed between alternate pits, and each capable of supplying two roads; they are of the ordinary type, and require no special notice.

Yard.—Passing out into the yard, Fig. 3, Plate 41, there are cross-over roads with compound shunts, so arranged as to lead the engines out from any of the ten shed-roads to the six main running lines that lead from the yard, or to the main coal-stage roads. There are three junctions to get from the yard to the main line.

The coal stage has a double platform, Fig. 3, with a road for the wagons in the centre, and a road on the outside of either platform for the engines. The platforms are $133\frac{1}{4}$ ft. long, and each is fitted with three coal-cranes and nine tumbler-buckets for working.

Sand Drying.—Between the coal cranes are placed tanks for containing dried sand; and in close proximity to the coal stage there is a sand-drying kiln U, Fig. 3. This has three furnaces, and the flues are so arranged as to heat 406 sq. ft. of drying platform, which is made of firebrick. The sand is first thrown in through doors in the front of the kiln, ranged above the stoke-plates, and is there received upon an inclined iron slide, the bottom end of which rests upon the front edge of the kiln; any excess of moisture in the sand runs down the slide and is at once converted into steam. The sand from the slide is cast and spread out upon the kilns; and in process of drying is gradually worked by hand across to the delivery side, where when dry it is cast upon a sloping screen, and the fine sand passing through is taken to the tanks upon the coal stage, the rough refuse being thrown out.

Water Supply. — The water used at this shed is pumped up from a well W, Fig. 3, by means of a Tangye "special" pump, which delivers it into a cast-iron tank, supported by wrought-iron girders that rest upon a stone building V. The bottom of the tank is 25 ft. above the ground. The well is 53 ft. depth, of which 7 ft. is subsoil, 9 ft. gravel, and 37 ft. marl. From this depth about 7000 gallons per hour are obtained.

Turntable.—The main girders of the turntable, Fig. 3, Plate 41, are semi-elliptic inverted, of riveted plate, and of treble T section, as shown in Figs. 11 and 12, Plate 43. The centre piece is supported by two short wrought-iron beams. The centre pivot is composed of a round wrought-iron pin, as shown to a larger scale in Fig. 13, supported by a cast-iron cone which rests upon the centre foundation stone. Between the top of the wrought-iron pin and the top cap is inserted a case-hardened washer of convex and concave section, to reduce the friction. The ends of the table are carried round the race upon four cast-iron wheels, two at either end, which are shod with crucible-steel tyres of 2 ft. 11$\frac{5}{8}$ ins. diameter. The short axles of the wheels run in plummer-blocks attached to cast-iron frames, which support the extreme ends of the table, Figs. 11 and 12. The

race is of ordinary double-headed steel rails, Figs. 14 and 15, fixed in special chairs with adjustable keys; the chairs are carried upon stone. Although this turntable is of the ordinary construction, it works so well without any cog gearing that the author thought the mention of it might be of interest.

Traverser.—The main frames of the traverser, Figs. 16 to 18, Plates 44 and 45, are composed of eighteen pairs of double-headed steel rails, laid transversely, and joined together by angle-iron and wrought-iron plate both diagonally and longitudinally, with cast-iron distance-pieces intervening, the whole riveted together both top and bottom: thus forming a broad shallow box-girder, upon which are laid the bridge-rails R that carry the locomotive. This box-girder is formed for a width of 9 ft. 9 ins.; but the double-headed rails are made to extend a distance of 3 ft. 10 ins. beyond on either side; and to these are attached the cast-iron bearing blocks, which carry the axles of the traverser wheels W. On the western side these rails are still further extended, so as to form a platform, upon which are carried the boiler B and engines E that work the machine. Upon the same side the axles of the bearing wheels are prolonged, so as to attach to them cog wheels C, Fig. 16, into which gear the main pinions of the driving engines, Fig. 18.

The driving engines are a pair of 8-inch cylinders with 12 ins. stroke; they have a suitable vertical boiler.

In working across the shed, the traverser runs into the western side recess, Fig. 1, Plate 40, which enables locomotives to be taken out of the building without passing through the northern half of the main shed. This arrangement also obviates the necessity of having large doors of the whole width of the traverser pit.

Roof.—The main roof framing, Fig. 4, Plate 41, is a compound of iron, both wrought and cast, with ties of mild steel. The covering is two-fifths of slates, laid upon wood planking, and three-fifths of rough ribbed glass in cast-iron frames. The whole of the engine roads are covered with smoke trunking, made of galvanised sheet-iron, 2 ft. 11 ins. wide by 3 ft. 5 ins. deep, and with outlet chimneys

carried up through the roof at intervals of 35 ft. 8 ins. All of these chimneys have holes cut in them just before they reach the roof, so as to draw off any smoke or steam which may have escaped into the roof.

In addition to the foregoing description of the running sheds, advantage may be taken of this opportunity for mentioning one or two smaller matters which may be worthy of attention in the working of locomotives.

Flange Lubricator.—A simple contrivance for lubricating the flanges of the leading wheels of an engine when running round curves is shown in Figs. 19 to 23, Plate 46. It is composed of three small vessels, one placed upon either side AA, and the third C in the centre of the leading end of the engine, under the footplate. The middle vessel C is a closed tank, which is connected with both the others by means of a $\frac{3}{8}$ inch copper pipe P. It is also connected with the tender or feed-water tank by another pipe T, on which is arranged a small inlet valve I, Fig. 22, worked by a float F in the vessel; and this float admits water up to a certain level L only. In each of the two side vessels is fixed a small stand-pipe S, Fig. 23, the top of which stands at a certain height above the ordinary water-level L, so that no water will flow out through it unless the water-level is raised above its top. From the stand-pipe a tube passes down to deliver the overflowing water on the flange of the leading wheel W.

To put the apparatus into working order, water is poured into all three vessels until it rises to a height L, at which the float F closes the inlet valve I. When the engine is running round a curve, the centrifugal force causes the water to flow towards the outside of the curve, where it rises in the vessel A at that side, and flows over the top of the stand-pipe S, and down to the wheel flange W. This continues till the engine leaves the curve; when the water will resume a uniform level in all three vessels, and the float F will drop and admit a supply to bring the level up to its normal height L.

Jet for Washing Rails.—For washing the road clean during dirty weather, a simple device, shown in Fig. 10, Plate 42, consists in supplying a very small jet of water J from the boiler, directed upon the rail in front of the driving wheels. This arrangement has been found most efficient during the past winter, and also saves a considerable quantity of sand.

High-Speed Air-Compressor.—Although not connected specially with locomotive engines, a small high-speed air-compressor, shown in Figs. 24 to 27, Plate 47, may be of some little interest, and will be seen by the members visiting the locomotive shops. It was designed some five or six years back for testing the effect of air mixed with steam, and was used for a few weeks. It has worked up to 120 revolutions per minute, and compressed air up to 250 lbs. per sq. inch, delivering at each stroke its whole volume of air, 75 cubic inches, without any loss through clearances, the cylinder being 4 ins. diameter and 6 ins. stroke. It is constructed on the principle of a water piston, sucking in and discharging again at each stroke a very small quantity of water. Curiously enough a very similar air-compressor has recently been brought out in Belgium, as something good and at the same time uncommon.

Discussion.

Mr. J. A. Haswell said there could be no doubt the most important consideration for a locomotive engineer in constructing an engine shed was whether he should use traversers or turntables. The paper just read described a long rectangular building, with a traverser working across the middle of its length. It appeared to him that there would often be a difficulty in getting engines out of a shed so constructed, inasmuch as, the entrance and exit being at one end only, many occasions must arise when it would be necessary to

(Mr. J. A. Haswell.)

bring out at least two engines before the one that was wanted could be got out. If the traverser in the middle of the shed should fail, he wanted to know how the engines could be got out from the further end, over the traverser that had failed. With the use of turntables, in a shed of either polygonal or rectangular shape, the turntables could be so arranged that there would be no difficulty at all in getting out any one engine without disturbing any others. The turntables might be so arranged that, even supposing one of them were out of order, there should still be three, four, and sometimes five ways available for getting the engines out of the shed. From his own experience of the large locomotive sheds of the North Eastern Railway, it was clear to himself that now and then great difficulties would be found in getting out the particular engines that were wanted from a shed such as that described in the paper. But in an engine shed of the same form, and having five turntables in it, from 90 to 100 engines could be housed; and if any one of the turntables were to break down, all the engines could still be got out except those standing behind the particular table that was out of order. Hence in sheds where turntables were used nothing like the amount of difficulty would be experienced that there would be in the shed described in the paper. At the same time he was quite ready to admit that there was more ground occupied with turntables than in the other plan.

Mr. T. HURRY RICHES said, the question of the economy of space having been conceded, the chief point was as to getting engines out from the inner end of the shed. Now it was well known that the question of vital importance in a steam shed was how to deal with the "day-in" engines. Before building this shed he had looked at a great many engine sheds, some more modern than others; and his idea was that where the day-in engines could be brought close against the shop, and their cylinders could be brought close up to the bench, it was far more convenient than placing eight or ten engines along the side of the shed, and then taking the chance of the outermost engine being rather later in finishing than any of the others, and consequently blocking the whole of that side of the

shed. The arrangement of the shed described in the paper enabled every engine to be taken out, other than the one that had to be detained for repairs; and his experience had been that this arrangement was far better than that of any shed he had had the pleasure of seeing on the other plan.

Mr. W. Barton Wright considered the most eligible arrangement for an engine shed depended very much on the nature of the traffic. In some sheds he thought there would be an inconvenience in having a traverser working right across the middle; and there was no doubt that, regardless of space, a series of turntables was a very great convenience, as any particular engine could thereby be got out at any time. But he had known one case of a round shed, containing only a single turntable, where the turntable broke down, and the whole of the engines were locked up in consequence; and if there were five turntables in a large shed, one-fifth of the engines might be locked up by one table breaking down. With a traverser it was customary to have beams in readiness, with rails upon them, so that in case of the traverser breaking down the engines could always be got out by placing the beams and rails across the traverser pit; he did not know whether the author used anything of that kind in case of an accident. A traverser he thought was less likely to break down than a turntable; but the inconvenience consequent upon a turntable breaking down depended entirely on the way in which the tables were arranged. For himself he should prefer placing the traverser at the inner end of the rectangular engine shed, instead of in the middle of its length.

Mr. E. Hamer Carbutt, M.P., asked how the traffic was worked, as he understood the Taff Vale traffic was worked very differently from that of any other line, for the reason that it was all down-hill traffic with heavy coal trains, and five or six trains were loaded up together, which were all started at intervals of only five minutes between them; so that all their engines would go out and come in at about the same time. For such a mode of working there was less difficulty in arranging in a longitudinal shed than in a circular one.

Mr. T. Hurry Riches replied that of course the engines were worked out of the shed very rapidly; and by keeping thirty engines in the front half of the shed, these thirty were always able to be got clear out without any obstruction from the others. Then as to the traverser, and the thirty engines standing behind it, the bottom or innermost tier were the day-in engines, and the two tiers in front of these were for what were called the eleven o'clock trains and the afternoon trains: so that there was always ample time to get them out if anything went wrong, particularly as the engines from behind the traverser were worked across one after another as the front roads were cleared. During the night there was always plenty of time to put things in order. As far as the traverser pit was concerned, it would be seen that it was a very shallow one, and a couple of timbers placed with rails on the top would at any time take the engines across. As to the relative risk of damage by getting engines into traverser and turntable pits, during the experience of twenty years two cases of each description had come under his observation: in each case where the engine went into a traverser pit no damage was done to either engine or traverser, and in each case twenty minutes sufficed to put the engine upon the road again; whereas in each case of an engine falling into a turntable pit several hours were occupied in getting her out again, and considerable damage was done both to the engine and to the turntable.

The coal trains were run in a series of thirty or forty at a time, one after the other about every three minutes; so that it would not matter much which engines went out first. The order in which they usually went out was that the whole of the ten engines in the first tier of berths lettered A were first taken out, right across the shed; so that these first engines had no obstruction. Next went the ten engines in the second tier; and so on. There were practically three depots at which to pick up trains: one was through the south junction at the docks; another was at the junction of the sidings outside the shed; and the further one was Penarth Junction, to pick up the traffic from the Penarth docks. The purpose of sending the engines out to those junctions was to prevent any obstruction to the traffic.

Mr. J. P. Fearfield mentioned one instance of an accident which he hoped was not within the experience of many. An engine standing behind a turntable in an engine shed had had the brake-blocks taken off without the driver being aware of it; and on his trying just to move the engine, simply to see that the cylinders and valve gear were all right, he was not able to stop it, and it fell into the turntable pit, which was a deep one; it was a very heavy job to get the engine out of the pit, and the engines in the shed were locked up for a long time because the turntable was completely wrecked. Had that engine shed been built with a traverser, it would have been far easier to lift the locomotive out of the shallow traverser pit; and the traverser would have been of use again immediately afterwards.

Mr. Joseph Tomlinson remarked that circumstances greatly altered cases; and those who knew what they wanted were the best to design what should be done. Having had something like forty years' experience of sheds with turntables and traversers, he had during the whole of that time had only one engine in a turntable pit. On the Midland Railway, where he was for four years, he had had some hundreds of engines daily worked on turntables, nearly all the sheds having turntables, and during all that time he never had an engine locked up. When an engine turntable or traverser wanted mending, it should be mended before it broke down; that was his experience in working engines, and he would never work them to break down, if he could help it. Mr. Riches having been a pupil of his, and having had a few ideas from him in his time, he thought he could see why he had done what he had in the present case, though this had not been told in the paper. He had not been able to obtain authority to build entirely new shops; and in order to get a little more repairing room he had therefore made the new shed into a combination of a running shed and a repairing shop, putting the traverser in so that he could get the engines in and lay them up for repairs at one end of the shed, and get them out at the other end for running. Some day or other, when he got new shops, he would convert this shed entirely into a running shed, shift the traverser from the middle to the inner end,

(Mr. Joseph Tomlinson.)

and work as many engines as he could out at the front end, leaving the others to come out over the traverser at the back end. Twelve years ago, when he was himself on the Taff Vale Railway, he had had as much as he could do to get through the work properly, and how Mr. Riches had done it since he did not know; the stock of engines had increased 40 or 50 per cent., and there had been no more room for them until this new shed was completed a few weeks ago; so that he supposed Mr. Riches must have done what he himself had had to do at the Edgware Road locomotive shops of the Metropolitan Railway before he got the new shops at Neasden—let the engines stand out on the main line all night.

The PRESIDENT said there had been a good deal of talk about locking up engines; but as one connected with the management of railways, he would point out that there was also something to be said about locking up money. A partial solution had been suggested by Mr. Tomlinson of the cause which had led to the adoption of the plan described in the paper—namely, that in point of fact it was the limitation of funds at Mr. Riches' disposal, and not his own will, which had consented to the traverser he had adopted. He was sure the Members would all cordially thank the author for his paper.

Mr. CHARLES H. RICHES has since supplemented his brother's replies to the remarks in the discussion by the following additional observations:—

With regard to the alleged difficulty in getting engines in and out of a running shed, where a traverser was used instead of turntables, it would be seen from the plan of the shed, Fig. 1, Plate 40, that any one of the thirty engines nearest the doors, upon the berths A, B, C, in front of the traverser, could be got out by removing only one engine at the most. Supposing that this front half of the shed was completely filled, the whole of the engines upon the berths A could pass straight out, without anything in front of them; and any engine upon the berths B could be got out by

simply moving the engine upon the berth A on the same road, or by taking out that upon C over the traverser. The road outside the western side of the shed admitted of engines passing in and out without interfering with the thirty engines in the front half nearest the doors: this disposed of the remark that the entrance and exit were at one end only. Then as to the inner half of the shed behind the traverser, none of the engines so placed were required out until at least the majority of those in the front half had left, and consequently until so many through roads had been cleared. Therefore the hinder engines had generally to pass simply straight over the traverser and out; but where the road immediately in front was blocked, they could, by being moved on the traverser, have the choice of any road that was clear. In the event of any failure of the traverser, a pair of half timbers with rails on top would convey any engines across the traverser pit, on account of its being so shallow. If turntables had been adopted, the same extent of accommodation could not have been supplied without a large increase in the first cost and maintenance of the shed; the increase in first cost was estimated at as much as one-fifth.

In reference to the advisability of putting the traverser at the innermost end of the shed, instead of in the middle of its length, to have done this would have involved six engines being placed in a continuous row upon each of the roads; and in case of failure of one of the front engines nearest the doors, five would have to be worked back over the traverser: in comparison with the present arrangement, which never required more than one engine to be moved in front of the traverser.

With regard to the question of "day-in" engines, there were every day from twelve to fifteen engines in for washing out and temporary repairs; and by the present plan all these were close up to the fitters' benches at the innermost end of the shed, and were capable of being taken out, each as it was finished, and berthed for their following day's work. But, were the traverser placed at the innermost end of the shed, that number of day-in engines would have to occupy two roads along the entire length of the shed, and no one of them could be moved until the temporary repairs were

(Mr. Charles H. Riches.)

completed upon each or all of the rest on the same road: thus preventing any from being marshalled or berthed until all were finished. Added to this, the fitters' benches would have to be arranged along the side of the shed; and the work upon the second tier of engines, such as rods, pistons, &c., would have to be carried across the nearest pit, and in some instances along the entire length of the shed. So that, looking at the question either from the point of working engines out, or repairing and washing, or cost to house per engine, the method adopted in the new running shed appeared the preferable one.

The object of putting the repairing shops at the inner end of the running shed was not for enabling general repairs to be done there; but as this running shed was at some distance from the fitting shops at the Cardiff terminus, any work required upon a day-in engine could now be dealt with in these small shops at Cathays, thus obviating the necessity of employing a pilot engine in carrying work backwards and forwards from the repairing shops at the Cardiff terminus. Of course so long as the running shed remained at the old site, the repairing shops were in such close proximity that it was unnecessary to have machines in the running shed.

DESCRIPTION OF THE FRANCKE "TINA" OR VAT PROCESS FOR THE AMALGAMATION OF SILVER ORES.

By Mr. EDGAR P. RATHBONE, of London.

In the year 1882, whilst on a visit to some of the great silver mines in Bolivia, an opportunity was afforded the writer of inspecting a new and successful process for the Treatment of Silver Ores, the invention of Herr Francke, a German gentleman long resident in Bolivia, whose acquaintance the writer had also the pleasure of making. After many years of tedious working devoted to experiments bearing on the metallurgical treatment of rich but refractory silver ores, the inventor has successfully introduced the process of which it is proposed in this paper to give a description, and which has, by its satisfactory working, entirely eclipsed all other plans hitherto tried in Bolivia, Peru, and Chili. The Francke "tina" process is based on the same metallurgical principles as the system described by Alonzo Barba in 1640, and also on those introduced into the States in more recent times under the name of the Washoe process.*

It was only after a long and careful study of these two processes, and by making close observations and experiments on other plans which had up to that time been tried with more or less success in Bolivia, Peru, and Chili—such as the Mexican amalgamation process technically known as the "patio" process, the improved Freiberg barrel amalgamation process, as used at Copiapo, and the "Kronke" process—that Herr Francke eventually succeeded in devising his new process, and by its means treating economically

* Transactions of the American Institute of Mining Engineers, vol. II., p. 159.

the rich but refractory silver ores, such as those found at the celebrated Huanchaca and Guadalupe mines in Potosi, Bolivia. In this description of the process, the writer will endeavour to enter as far as possible into details having a practical bearing on the final results; and with this view will commence with the actual separation of the ores at the mines.

Ore Dressing, etc.

This consists simply in the separation of the ore by hand at the mines into different qualities, by women and boys with small hammers, the process being that known as "cobbing" in Cornwall. The object of this separation is twofold: firstly to separate the rich parts from the poor as they come together in the same lump of ore, otherwise rich pieces might go undetected; and secondly to reduce the whole body of ore coming from the mine to such convenient size as permits of its being fed directly into the stamps battery. The reason for this separation not being effected by those mechanical appliances so common in most ore-dressing establishments, such as stone breakers or crushing rolls, is simply because the ores are so rich in silver, and frequently of such a brittle nature, that any undue pulverisation would certainly result in a great loss of silver, as a large amount would be carried away in the form of fine dust. So much attention is indeed required in this department that it is found requisite to institute strict superintendence in the sorting or cobbing sheds, in order to prevent as far as practicable any improper diminution of the ores. According to the above method the ores coming from the mine are classified into the four following divisions:—

I. Very rich ore, averaging about 6 per cent. of silver, or containing say 2000 ounces of silver to the ton (of 2000 lbs.).

II. Rich ore, averaging about 1 per cent. of silver, or say from 300 to 400 ounces of silver to the ton.

III. Ordinary ore, averaging about ½ per cent. of silver, or say from 150 to 200 ounces of silver to the ton.

IV. Gangue or waste rock, thrown on the dump heaps.

The first of these qualities—the very rich ore—is so valuable as to render advantageous its direct export in the raw state to the coast for shipment to Europe. The cost of fuel in Bolivia forms so considerable a charge in smelting operations that the cost of freight to Europe on very rich silver ores works out at a relatively insignificant figure when compared with the cost of smelting operations in that country. This rich ore is consequently selected very carefully and packed up in tough raw hide bags, so as to make small compact parcels some 18 inches to 2 feet long, and 8 to 12 inches thick, each containing about 1 cwt. Two of such bags form a mule load, slung across the animal's back.

The second and third qualities of ore are taken direct to the smelting works; and where these are situated at some distance from the mines, as at Huanchaca and Guadalupe, the transport is effected by means of strong but lightly built iron carts, specially constructed to meet the heavy wear and tear consequent upon the rough mountain roads. These two classes of ores are either treated separately, or mixed together in such proportion as is found by experience to be most suitable for the smelting process.

On its arrival at the reduction works the ore is taken direct to the stamp mill. At the Huanchaca works there are sixty-five heads of stamps, each head weighing about 500 lbs., with five heads in each battery, and crushing about 50 cwts. per head per 24 hours. The ore is stamped dry, without water, requiring no coffers; this is a decided advantage as regards first cost, owing to the great weight of the coffers, from 2 to 3 tons—a very heavy item when the cost of transport from Europe at about £50 per ton is considered. As fast as the ore is stamped, it is shovelled out by hand, and thrown upon inclined sieves of 40 holes per lineal inch; the stuff which will not pass through the mesh is returned to the stamps.

Dry stamping may be said to be almost a necessity in dealing with these rich silver ores, as with the employment of water there is a great loss of silver, owing to the finer particles being carried away in suspension, and thus getting mixed with the slimes, from

which it is exceedingly difficult to recover them, especially in those remote regions where the cost of maintaining large ore-dressing establishments is very heavy. Dry stamping however presents many serious drawbacks, some of which could probably be eliminated if they received proper attention. For instance, the very fine dust, which rises in a dense cloud during the operation of stamping, not only settles down on all parts of the machinery, interfering with its proper working, so that some part of the battery is nearly always stopped for repairs, but is also the cause of serious inconvenience to the workmen. At the Huanchaca mines, owing to the presence of galena or sulphide of lead in the ores, this fine dust is of such an injurious character as not unfrequently to cause the death of the workmen; as a precautionary measure they are accustomed to stuff cotton wool into their nostrils. This however is only a partial preventive; and the men find the best method of overcoming the evil effect is to return to their homes at intervals of a few weeks, their places being taken by others for the same periods. In dry stamping there is also a considerable loss of silver in the fine particles of rich ore which are carried away as dust and irrevocably lost. To prevent this loss, the writer proposed whilst at Huanchaca that a chamber should be constructed, into which all the fine dust might be exhausted or blown by a powerful fan or ventilator.

Roasting.

From the stamps the stamped ore is taken in small ore-cars to the roasting furnaces, which are double-bedded in design, one hearth being built immediately above the other. This type of furnace has proved, after various trials, to be that best suited for the treatment of the Bolivian silver ores, and is stated to have been found the most economical as regards consumption of fuel, and to give the least trouble in labour.

At the Huanchaca mines these furnaces cost about £100 each, and are capable of roasting from 2 to 2½ tons of ore in twenty-four hours, the quantity and cost of the fuel consumed being as follows :—

	Bolivian Dollars at 3*s.* 1*d.*
Tola (a kind of shrub), 3 cwts. at 60 cents . .	1·80
Yareta (a resinous moss), 4 cwts. at 80 cents . .	3·20
Torba (turf), 10 cwts. at 40 cents . . .	4·00
Bolivian Dollars . .	9·00 say 28*s.*

One man can attend to two furnaces, and earns 3*s.* per shift of twelve hours.

Probably no revolving mechanical furnace is suited to the roasting of these ores, as the operation requires to be carefully and intelligently watched; for it is essential to the success of the Francke process that the ores should not be completely or "dead" roasted, inasmuch as certain salts prejudicial to the ultimate proper working of the process are liable to be formed if the roasting be too protracted. These salts are mainly due to the presence of antimony, zinc, lead, and arsenic, all of which are unfavourable to amalgamation.

The ores are roasted with 8 per cent. of salt, or 400 lbs. of salt for the charge of 2½ tons of ore; the salt costs 70 cents or 2*s.* 2*d.* per 100 lbs. So roasted the ores are only partially chlorinised, and their complete chlorinisation is effected subsequently, during the process of amalgamation; the chlorides are thus formed progressively as required, and in fact it would almost appear that the success of the process virtually consists in obviating the formation of injurious salts. All the sulphide ores in Bolivia contain sufficient copper to form the quantity of cuprous chloride requisite for the first stages of roasting, in order to render the silver contained in the ore thoroughly amenable to subsequent amalgamation.

Amalgamating.

From the furnaces the roasted ore is taken in ore-cars to large hoppers or bins situated immediately behind the grinding and amalgamating vats, locally known as "tinas," into which the ore is run from the bin through a shoot fitted with a regulating slide. The

tinas or amalgamating vats constitute the prominent feature of the Francke process; they are large wooden vats, shown in Figs. 1 and 2, Plate 48, from 6 to 10 feet diameter and 5 feet deep, capacious enough to treat about $2\frac{1}{2}$ tons of ore at a time. Each vat is very strongly constructed, being bound with thick iron hoops. At the bottom it is fitted with copper plates about 3 inches thick, C in Fig. 1; and at intervals round the sides of the vat are fixed copper plates P, as shown in Figs. 3 and 4, Plate 49, with ribs on their inner faces, slightly inclined to the horizontal, for promoting a more thorough mixing. It is considered essential to the success of the process that the bottom plates should present a clear rubbing surface of at least 10 square feet.

Within the vat, and working on the top of the copper plates C, there is a heavy copper stirrer or muller M, Figs. 1 and 2, caused to revolve by the shaft S at the rate of 45 revolutions per minute. At Huanchaca this stirrer has been made with four projecting radial arms AA, Figs. 1 and 2; but at Guadalupe it is composed of one single bell-shaped piece B, Figs. 3 and 4, without any arms, but with slabs like arms fixed on its underside; and this latter is claimed to be the most effective. The stirrer can be lifted or depressed in the vat at will by means of a worm and screw W at the top of the driving shaft, Fig. 3.

The bevel gearing of the stirrer shaft is revolved by shafting connected with pulley wheels and belting, the wheels being 3 ft. and $1\frac{1}{2}$ ft. diameter, and 6 ins. broad. The driving engine is placed at one end of the building. Each vat requires from $2\frac{1}{2}$ to 3 HP., or in other words an expenditure of one HP. per ton of ore treated.

At the bottom of the vat and in front of it a large wooden stop-cock is fitted, through which the liquid amalgam is drawn off at the end of the process into another shallow-bottomed and smaller vat V, Figs. 1 and 2. Directly above this last vat there is a water-hose H, supplied with a flexible spout, through which a strong stream of water is directed upon the amalgam as it issues from the grinding vat, in order to wash off all impurities.

The following is the mode of working usually employed. The grinding vat or tina is first charged to about one-fifth of its depth

with water and from 6 to 7 cwts. of common salt. The amount of salt required in the process depends naturally on the character of the ore to be treated, as ascertained by actual experiment, and averages from 150 to 300 lbs. per ton of ore. Into this brine a jet of steam is then directed, and the stirrer is set to work for about half-an-hour, until the liquid is in a thoroughly boiling condition, in which state it must be kept until the end of the process.

As soon as the liquid reaches boiling point, the stamped and roasted ore is run into the vat, and at the end of another half-hour about 1 cwt. of mercury is added, further quantities being added as required at different stages of the process. The stirring is kept up continuously for 8 to 12 hours, according to the character and richness of the ores. At the end of this time the amalgam is run out through the stop-cock at bottom of the vat, is washed, and is put into hydraulic presses, by means of which the mercury is squeezed out, leaving behind a thick pulpy mass, composed mainly of silver, and locally termed a "piña," from its resembling in shape the cone of a pine-tree. These "piñas" are then carefully weighed and put into a subliming furnace, Figs. 5 and 6, Plate 50, in order to drive off the rest of the mercury, the silver being subsequently run into bars. About four ounces of mercury are lost for every pound of silver made.

The actual quantities of mercury to be added in the grinding vat, and the times of its addition, are based entirely on practical experience of the process. With ore assaying 150 to 175 ounces of silver to the ton, 75 lbs. of mercury are put in at the commencement, another 75 lbs. at intervals during the middle of the process, and finally a third lot of 75 lbs. shortly before the termination. When treating "pacos" or earthy chlorides of silver, assaying only 20 to 30 ounces of silver to the ton, mercury is added in instalments of 36 lbs. to $2\frac{1}{2}$ tons of ore at three different stages of the process as just described.

The rationale of the process therefore appears to be that the chlorinisation of the ores is only partially effected during the roasting, so as to prevent the formation of injurious salts, and is completed in the vats, in which the chloride of copper is formed

progressively as required, by the gradual grinding away of the copper by friction between the bottom copper plates and the stirrer; and this chloride subsequently becoming incorporated with the boiling brine is considered to quicken the action of the mercury upon the silver.

Subliming.

The subliming furnace, shown in Figs. 5 and 6, Plate 50, is a plain cylindrical chamber A, about 4 ft. diameter inside and 4½ ft. high, lined with fire-brick, in the centre of which is fixed the upright cast-iron cylinder or bell B of 1 ft. diameter, closed at top and open at bottom. The furnace top is closed by a cast-iron lid, which is lifted off for charging the fuel. Round the top of the furnace is a tier of radial outlet holes for the fuel smoke to escape through; and round the bottom is a corresponding tier of inlet air-holes, through which the fuel is continually rabbled with poles by hand. The fuel used is llama dung, costing 80 cents or 2*s.* 6*d.* per 250 lbs.; it makes a very excellent fuel for smelting purposes, smouldering and maintaining steadily the low heat required for subliming the mercury from the amalgam. Beneath the furnace is a vault containing a wrought-iron water-tank W, into which the open mouth of the bell B projects downwards and is submerged below the water. For charging the bell, the water-tank is placed on a trolly; and standing upright on a stool inside the tank is placed the piña, or conical mass of silver amalgam, which is held together by being built up on the core-bar C fitted with a series of horizontal discs. The trolly is then run into the vault, and the water-tank containing the piña is lifted by screw-jacks, so as to raise the piña into the bell, in which position the tank is then supported by a cross-beam. The sublimed mercury is condensed and collected in the water; and on the completion of the process the tank is lowered, and the spongy or porous cone of silver is withdrawn from the bell. The subliming furnaces are ranged in a row, and communicate by lines of rails with the weigh house.

Discussion.

The President said a letter had been received from Mr. R. J. Frecheville, of Truro, one of H. M. Inspectors of Mines, who not being able to be present had kindly sent some observations on the contents of the paper.

Mr. R. J. Frecheville wrote as follows:—"I regret very much that I shall be unable to attend the Meeting to take part in the discussion on Mr. Rathbone's paper, as having had some years' practical experience in the treatment of silver ores in the Western States of America I take great interest in this special branch of metallurgy. After reading the paper, there are still a few points on which it is necessary to be enlightened, in order to be able to estimate the value of the process described. Also a few suggestions occur to me:—first of all, what are the silver and associated minerals contained in the ore? and of what is the gangue composed?

"In the classification of the ore, there is a very great difference between the third division averaging from 150 to 200 oz. of silver per ton, and the fourth division constituting waste rock thrown on the dumps. This is the more remarkable as cobbing and hand-sorting only are resorted to. It would be desirable to know whether assays are made of the waste rock; and if so, what are the average silver contents per ton?

"The ore is described as being stamped dry without coffers. Has the loss in dust ever been ascertained? It must be enormous. As regards coffers being inadmissible owing to heavy rates of freight from Europe, they could very well be constructed of wood; of course they would wear out fast, but they would pay for themselves over and over again by preventing to a large extent the loss in dust; and being fitted with sieves in the usual manner, they would do away with the labour of throwing the crushed ore over inclined screens, and the further loss in dust thus occasioned. In the United States, where the dry stamping of silver ores is largely practised, the battery housings are connected with dust chambers by stove piping; the necessary draught is produced by an exhaust fan, and is regulated for each battery by a damper.

(Mr. R. J. Frecheville.)

"It is not stated in the paper whether assays are made to determine to what extent the silver in the ores is chloridised before amalgamation; but as 8 per cent. of salt is added, and one furnace roasts only $2\frac{1}{2}$ tons of ore per twenty-four hours, if sulphides are present in sufficient quantity, as would seem to be the case, the percentage of chloride produced would be as high as is usually obtained. The ordinary practice is to raise the heat towards the end of the roasting so as to decompose and volatilise the base metal chlorides, as they act injuriously by flouring and sickening the mercury in the subsequent amalgamation; but as considerable chloride of silver will escape with them, it is necessary to strike a very nice balance. The point of interest in the roasting at the Huanchaca mines is whether it is stopped when the highest percentage of chloride of silver is obtained, without reference to the condition of the base metals; or whether it is attempted to strike the nice balance above referred to. The loss of mercury, which the author states as being about 4 oz. per lb. of silver produced in treating ore assaying 200 oz. of silver per ton, leads me to believe the former. This loss is equivalent to about 4 lbs. of mercury per ton of ore treated—a heavy loss even in treating base silver ores, the worst feature of it being that this escaping mercury contains a considerable amount of dissolved silver.

"Since the base metal chlorides are soluble in water, the difficulty in amalgamation caused by their presence could be got rid of by previously leaching the roasted ore with hot water. Some chloride of silver would be dissolved, owing to the presence of these soluble chlorides and of undecomposed salt in the roasted ore; but only a very small quantity, if the water were first conveyed into the washing tanks under a slight pressure from below. In this way the solution containing dissolved silver would be diluted with fresh water before leaving the tanks; and the silver chloride would be deposited in the ore, as it is soluble in a strong solution of brine but is precipitated on diluting the solution. The first wash would also be reserved for separate treatment. The extra expense of this process would be more than repaid by the better results obtained in the subsequent amalgamation.

"From the description of the tina or amalgamating vat, it seems to be very much like the ordinary pan, except that it is constructed of wood and copper instead of being made of iron. The chloride of copper, formed by the action of the boiling brine and friction on the copper, is produced in the common amalgamating pan by the addition of salt and sulphate of copper to the charge. Both copper and iron would precipitate the dissolved silver in the metallic state, so as to bring it within the influence of the mercury. The tina may however have an advantage over the iron pan, because the copper surfaces would become amalgamated, and in this condition would catch the fine particles of silver amalgam disseminated through the pulp, which particles would then be dissolved off by the rolling masses of mercury. It is considered by many of the best authorities that electricity has a great deal to do with the decomposition of the silver minerals in the pan process. If this is the case, the energy of the electric current between the mercury and copper would be superior to that between the mercury and iron. On the whole I am disposed to think the tina may be a very good amalgamator. As compared with the iron pan however, the tina must be a very poor grinder; and since hard lumps are formed even with the most careful roasting, no satisfactory amalgamation could result unless preceded by a thorough grinding of the roasted ore to the state of an impalpable mud. Grinding would take place in the tina, but it would necessarily be imperfect, and would be accompanied by a great wear of the copper surfaces. In this connection it would be interesting to know how long the copper mullers and bottoms of the tinas last. If the roasted ore were first ground in an ordinary iron pan, and then discharged into the tina for amalgamation, it would I think be a decided improvement.

"The author does not state what percentage of the silver contents of the ore is obtained by the process described, what is the average assay value of the tailings, or what is the fineness of the bullion produced. These are essential points to take into consideration."

Mr. T. R. CRAMPTON considered the question of dealing with rich ores was a very important one, and must be interesting to mechanical

(Mr. T. R. Crampton.)
engineers. It appeared to him that for many years there had been a want of appreciation of what was actually required in crushing such minerals. Crushing "fine" was talked about; but what "fine" meant he did not exactly know. It was true the paper mentioned sieves with 40 holes per lineal inch; but in practice he believed it was found the stamped ore would not go through a sieve finer than about 20 holes to the inch. In using sieves with about 40 holes to the inch, it was found they soon wore out, the holes got enlarged and became all kinds of sizes and shapes, so that the material was not obtained of the fineness required. In the letter from Mr. Frecheville it was mentioned that in the United States the dust made in dry stamping was drawn off by an air draught; but he understood this was done simply to get rid of the dust that was made, and not for the purpose of sifting the fine stuff. Within the last few months he had seen grinding done by a revolving disintegrator, by which 6 cwts. of gold quartz were ground per hour, though it was very hard stuff indeed; the cost of pulverising it was roughly about 16*d*. or 18*d*. a ton, and it was reduced so fine that every part of it passed through a sieve of 100 holes per lineal inch. There were two sets of arms, one set revolving in one direction and the other in the contrary, and the ore fed in from the outside was struck by the arms and pulverised. There were also blades on the arms, which produced an air current that carried the finest dust into a chamber, where it deposited. The rest of the stuff passed down to the bottom of the machine, whence it was taken up by an elevator and thrown into the top of the machine again. The working was perfectly automatic; none of the fine dust was sifted at all, but it was all fine enough to go through the sieve of 100 holes per inch. Such fine material required no subsequent grinding, and had been amalgamated without any grinding whatever, the mercury being merely passed through the dust itself. It was well known that all founders used dust coal for mixing with their sand; and some who took care to use none that was not fine enough to pass through a sieve of at least 100 holes per lineal inch had consequently acquired a high reputation for their castings. During the last few years this had been the practice at Woolwich Arsenal, where the pulverisation of the coal was effected

practically in the same way that he had described for gold quartz; in the shot and shell foundry one of these disintegrators had now been at work for four years, and had given the utmost satisfaction. He would suggest to founders in general that they should take more pains to get very fine dust.

Mr. Perry F. Nursey did not know why there should be any difficulty in grinding to the required degree of fineness. From 1852 to 1857 he had been connected with some gold-mining operations at North Molton, in Devonshire, where crushing machinery was put up. The matrix was gozzan, being the outcrop of a copper lode. In the first instance the apparatus used was simply a pair of edge runners, which crushed the ore in contact with mercury, and the crushed material was run out by the aid of a stream of water through wire-gauze sieves with 80 meshes per lineal inch or 6400 per square inch. That was about the mesh then used for the finest flour; but finer was used now. No difficulty was found; the wire gauze stood a long time, and worked very well. That simple apparatus was subsequently superseded by what was known as Perkes' machine, which had conical revolving grinders inside a cylinder, and was worked in the same way as the edge runners. Better results were obtained with that machine as regarded the yield of gold, and through the same meshes. As to the operations of the mine, no very good results were obtained commercially, although the mechanical arrangements were very perfect: £20,000 was spent, and about £50 worth of gold was got.

The President said it was of course very inconvenient to have a paper read in the absence of the author; but he understood Mr. Rathbone, who had been summoned abroad, had fully expected to get back in time for the present meeting, but had found himself unable to do so. The Members would all join in thanking him for his paper.

Mr. Rathbone, regretting that, owing to his prolonged detention on business in the United States, he was unable to attend the meeting as he had expected to do, has since sent the following remarks in reply to the observations made in the discussion. He wishes to mention that the notes for the paper were collected under difficulties of temporary illness consequent upon the high altitude in the Andes, which precluded his staying more than one day in the place.

The silver ores of Potosi are principally made up of what he believes to be a massive kind of stephanite (Ag_5 Sb S_4) with a large admixture of a variety of fahl-erz, that is, copper ore associated with arsenic and antimony and generally containing a little silver. The gangue consists principally of sparry matter and schistose rocks. Assays are made of the waste stuff thrown on the dumps; still no doubt a large amount of rich ore is lost there. He is not aware of any special experiments having been made to find out the loss in dust from the stamp mills; but quite agrees that the saving realised by the plan of using coffers, as is the custom in the States, with the new improvements of dust-chambers and stove-piping and exhaust-fan, would fully equalise the first extra cost due to the transport and extra weight of castings.

The point at which the roasting of the sulphides is stopped, he believes, is when the highest percentage of chloride of silver is obtained; and no attempt is made to strike a nice balance.

With Mr. Frecheville's views on leaching he fully agrees, believing that the best and most economical process for treating these ores is probably that of leaching; and should the process prove successful that has been tried in the States of late years, notably in Mexico, known as Russell's process for the lixiviation of silver ores, on which a paper by Mr. C. A. Stetefeldt was read at the Cincinnati meeting of the American Institute of Mining Engineers in May of this year, he considers it will be found much superior to that described in the present paper.

As to the similarity between the ordinary pan amalgamating process used in the States and the tina process of Herr Francke, no doubt there is very little that is new in the latter, except that the mullers and pans are here made and lined with copper, and also

that in the inventor's opinion the grinding action between the copper surfaces actually produces with the hot brine the chloride of copper which is said to facilitate so much the proper amalgamation of the silver. It must not be forgotten that the ore has been previously pulverised to a very fine powder before it is put into the amalgamating vat: it is first stamped fine, then roasted, and then mixed with the salt and mercury in the vat; so that the real purpose of the muller or stirrer appears to be not so much that of grinding the ore finer as of mixing it thoroughly with the mercury and hot brine, while at the same time the friction between the copper surfaces, wearing them away, gives rise to the gradual formation of chloride of copper in proportion as it is required for facilitating the amalgamation of the silver.

By this process the average percentage of silver obtained from the ore is $\frac{1}{2}$ per cent., or about 150 ounces to the ton. The average assay value of the tailings is about 20 ounces of silver to the ton. As to the fineness of the bullion produced, the author has no information.

As to fine pulverisation, while fully appreciating the importance of this part of the subject, he would point out the practical necessity, in dealing with very rich silver ores, of not pulverising too fine, because if the ores were reduced too fine there would be a great loss of silver in the tailings; it is therefore most desirable to crush such ores as little as possible. As to the extent to which the pulverisation of ores can be carried in works, no doubt great improvements have been made of late years in this direction; but it is questionable how far such fine pulverisation is economical, because not only are many of the pulverising machines liable to fracture and in need of frequent repairs, but so much extra handling of the stuff is also necessitated. It is therefore well not to lay down any general rule as to what process is good for all cases; but to try to find out what is most suitable and economical for any given circumstances and locality, and for any given character of ore and gangue.

ON THE USE OF PETROLEUM REFUSE AS FUEL IN LOCOMOTIVE ENGINES.

By Mr. THOMAS URQUHART, of Borisoglebsk, Russia.

The object of the present paper is to bring before the Institution the results of the author's experience in the extensive use of Petroleum Refuse as fuel in the locomotives under his charge on the Grazi and Tsaritsin Railway, South East Russia. In 1874 the first experiments in Russia with petroleum as fuel for locomotives were made on this railway;* but owing to its great cost at that time, although found in other respects capable of being used as a fuel, it was abandoned as uneconomical. Recently several appliances, the details of which are sufficiently well known, have been invented for utilising liquid fuel for locomotive and other boilers, and have been attended with more or less success.† A few of the most approved plans were tested on the Grazi and Tsaritsin Railway under the author's superintendence, thus affording him an excellent opportunity of becoming thoroughly acquainted with their working.

Petroleum.—The capabilities of liquid hydro-carbon as fuel, and the method of its employment, are but little known in Europe, its use being confined almost entirely to South East Russia, the only country in the continent of Europe where it is found in very great quantities. Besides Russia, the chief countries in which it is at present found are North America, Roumania, Hanover, Burmah (Rangoon), Australia, Galicia, and Africa; but where it may ultimately be found in large quantities it is difficult to say. Crude petroleum is found in large quantities at Baku on the south western shore of the Caspian Sea. The method invariably followed for its extraction is

* See Mr. Harrison Aydon's paper on Liquid Fuels, Institution of Civil Engineers, Proceedings 1878, vol. lii., page 188.

† See "Engineering" of 22 and 29 June 1883, pages 578 and 600.

to sink a bore-hole similar to an artesian well, but of larger dimensions. Cases occur almost annually of petroleum gushing forth from the wells like a fountain and under great pressure, spouting sometimes to a height of from 50 to 75 feet with a diameter at its issue of from 10 to 15 inches. Such a fountain flows uncontrollably for weeks together, flooding all the immediate vicinity and forming regular lakes of petroleum. This oil is called "lake petroleum," and has the peculiarity that the more volatile matter evaporates after some time of settling, and what is left is not so gaseous. At Balaxna (Black Town), near Baku, there are many large distilling establishments for manufacturing kerosine, benzine, photogen, &c., from crude petroleum. The by-products or refuse are used for the manufacture of lubricating oils, but more generally as fuel. In Russia the quantity of refuse in proportion to the distilled kerosine is very great; the finest kerosine amounts to only about 25 per cent. of the original weight of crude oil used, and ordinary commercial kerosine to only about 30 per cent., the remaining 70 to 75 per cent. being therefore available as fuel. Throughout the present paper it will be understood that the petroleum refuse spoken of by the writer as burnt in his locomotives is the first residue after the kerosine oil for burning in lamps has been distilled off; it is generally known in Russia as naphtha residue or refuse. Whether owing to the original chemical composition of raw petroleum or to the method of kerosine manufacture, the results are very different in America; there ordinary kerosine for illuminating purposes as produced from the Pennsylvanian crude oil amounts to from 70 to 75 per cent. of crude oil used. Yet the chemical composition of Pennsylvanian and of Russian crude oil is so nearly the same, as seen by the comparative statement tabulated below, that such a great difference would scarcely be expected in the distilled product, if the crude oil were treated in a similar manner.

Much has already been published as to the efficiency of hydro-carbon liquid fuels; but the writer is of opinion that a good deal remains to be made clear on the subject. Comparing naphtha refuse and anthracite, the former has a theoretical evaporative power of

Pennsylvanian and Russian Crude Petroleum Oil.

Crude Petroleum Oil.	PENNSYLVANIAN.	RUSSIAN.		
		Light.	Heavy.	Naphtha Refuse.
	per cent.	per cent.	per cent.	per cent.
Carbon . . .	84·9	86·3	86·6	87·1
Hydrogen . .	13·7	13·6	12·3	11·7
Oxygen . . .	1·4	0·1	1·1	1·2
	100·0	100·0	100·0	100·0
Specific Gravity at 32° Fahr. (water = 1·000) . .	0·886	0·884	0·938	0·928
Heating Power, British thermal units . . .	19,210 units	22,628 units	19,440 units	19,260 units
Theoretical Evaporation at 8 atm. pressure, in lbs. of water per lb. of fuel	16·2 lbs.	17·4 lbs.	16·4 lbs.	16·2 lbs.

16·2 lbs. of water per lb. of fuel, and the latter of 12·2 lbs., at an effective pressure of 8 atm. or 120 lbs. per sq. inch; hence petroleum has, weight for weight, 33 per cent. higher evaporative value than anthracite. Now in locomotive practice a mean evaporation of from 7 to 7½ lbs. of water per lb. of anthracite is about what is generally obtained, thus giving about 60 per cent. of efficiency, while 40 per cent. of the heating power is unavoidably lost. But with petroleum an evaporation of 12·25 lbs. is practically obtained, giving $\frac{12 \cdot 25}{16 \cdot 2}$ = 75 per cent. efficiency. Thus in the first place petroleum is theoretically 33 per cent. superior to anthracite in evaporative power; and secondly, its useful effect is 15 per cent. greater, being 75 per cent. instead of 60 per cent.; while thirdly, weight for weight, the practical evaporative value of petroleum must be reckoned as at least from $\frac{12 \cdot 25 - 7 \cdot 50}{7 \cdot 50}$ = 63 per cent. to $\frac{12 \cdot 25 - 7 \cdot 00}{7 \cdot 00}$ = 75 per cent. higher than that of anthracite.

Spray Injector.—Steam, not superheated, being the most convenient for injecting the spray of liquid fuel into the furnace, it remains to be proved how far superheated steam or compressed air is really superior to ordinary saturated steam, taken from the highest point inside the boiler by a special internal pipe. In using several systems of spray injectors for locomotives, the author invariably noticed the impossibility of preventing leakage of tubes, accumulation of soot, and inequality of heating of the fire-box. The work of a locomotive boiler is very different from that of a marine or stationary boiler, owing to the frequent changes of gradient on the line, and the frequent stoppages at stations. These conditions render firing with petroleum very difficult; and were it not for the part played by properly arranged brickwork inside the fire-box, the spray jet alone would be quite inadequate.

Hitherto the efforts of engineers have been mainly directed towards arriving at the best kind of "spray injector," for so minutely subdividing a jet of petroleum into a fine spray, by the aid of steam or compressed air, as to render it inflammable and of easy ignition. For this object nearly all the known spray-injectors have very long and narrow orifices for petroleum as well as for steam; the width of the orifices does not exceed from $\frac{1}{2}$ mm. to 2 mm. or 0·02 to 0·08 inch, and in many instances is capable of adjustment. With such narrow orifices it is clear that any small solid particles which may find their way into the spray-injector along with the petroleum will foul the nozzle and check the fire. Hence in many of the steamboats on the Caspian Sea, although a single spray-injector suffices for one furnace, two are used, in order that when one gets fouled the other may still work; but of course the fouled orifices require incessant cleaning out.

The construction of the spray-injector, as shown in Figs. 16 and 17, Plate 57, is very simple; in fact its great simplicity is its peculiar feature, and its merit is enhanced by the facilities it affords for stopping the fire at a moment's notice, as well as for regulating it to the utmost nicety during running or when standing at stations, in accordance with the demands made upon the boiler.

The combustion chamber, shown in Figs. 7, 8, and 11, Plates 54 and 56, is constructed with brickwork inside it, which when heated acts as a regenerator; through the brickwork are made as many channels or gas passages as are compatible with a sufficiently substantial structure. The brickwork thus offers a slight resistance to the free exit of the ignited gases, and so retains them as long a time as possible in the combustion chamber and fire-box, securing their thorough admixture with the air, as well as a long circuit before they enter the tubes.

The several drawings, Figs. 7 to 12, Plates 54 to 56, represent the arrangements adopted for securing the best results, the principle remaining the same in every case. Figs. 7, 8, and 11 show the plan that is found one of the best suited for locomotives. In Figs. 9, 10, and 12 is shown an arrangement intended for heating as hot as possible the portion of air that is introduced through the forward ash-pan damper, by passing it up through a narrow vertical channel A in the brickwork; an appreciable difference in results has been noticed with this method, simply from the fact that the air is considerably heated.

The only instance in which the author is using cold air for diffusing the spray is in the case of a special fire, shown in Figs. 20 and 21, Plate 59, arranged without a regenerator, for heating tyres; the ordinary blast is employed from the smithy main, being supplied by a Root's blower. In this arrangement the cost for fuel is only one-third of what it used to be with bituminous coal, while the amount of work done per day has been increased by 25 per cent. The four spray nozzles are arranged tangentially to the tyre, thus securing a circulation of flame all round. The appliances used for this open petroleum fire were not specially made for the purpose; the boxes previously employed for coal, shown in Figs. 22 and 23, were merely arranged to suit petroleum; the drawing therefore simply shows the main principle.

Locomotives.—In arranging a locomotive for burning petroleum, several details are required to be added in order to render the application convenient. In the first place, for getting up steam to begin

with, a gas-pipe G, Fig. 3, Plate 51, of 1 inch internal diameter is fixed along the outside of the boiler; and towards the middle of its length it is fitted with a three-way cock N having a screw-nipple and cap. The front end of the longitudinal pipe G is connected to the blower in the chimney, and the back end is attached to the spray injector. Then by connecting to the nipple N a pipe from a shunting locomotive under steam, the spray jet is immediately started by the borrowed steam, by which at the same time a draught is also maintained in the chimney. In a fully equipped engine-shed the borrowed steam would be obtained from a fixed boiler conveniently placed and specially arranged for the purpose of raising steam. In practice steam can be raised from cold water to 3 atm. pressure (45 lbs. per sq. inch) in twenty minutes. The use of auxiliary steam is then dispensed with, and the spray jet is worked by steam from its own boiler; a pressure of 8 atm. (120 lbs.) is thus obtained in 50 to 55 minutes from the time the spray jet was first started. In daily practice, when it is only necessary to raise steam in boilers already full of hot water, the full pressure of 7 to 8 atm. is obtained in from 20 to 25 minutes.

While experimenting with liquid fuel for locomotives, a separate tank was placed on the tender for carrying the petroleum, having a capacity of about 3 tons. But to have a separate tank on the tender, even though fixed in place, would be a source of danger, from the possibility of its moving forwards in case of collision. It was therefore decided, as soon as petroleum firing was permanently introduced, to place the tank for fuel in the tender between the two side compartments of the water-tank, as shown in Fig. 5, Plate 53, utilising the original coal-space. In this way a considerable saving in cost is obtained, besides greater safety. As three sides of the petroleum tank already existed, all that was required was to put a bulkhead in front, and to plate the top and bottom, thus giving the tender a flat top or platform appearance. One advantage arising from this arrangement is that in winter, while heating the water in the tender, the heat is transmitted to the petroleum through the two sides and rear end of the tank. But in addition it is also indispensable to place a warming coil of steam-pipe C close by the

outlet oil-valve V in the tank; through this coil a constant small upward flow of steam is maintained, entering at the bottom, and issuing into the air at T at one side of the top of the tender, so that the driver can always see that steam is really passing through the coil. This warming is always necessary when the air-temperature falls to about 12° Fahr. below freezing point. The small warming pipe S supplying steam to the coil has an elastic connection between tender and engine, and runs along inside the straight part of the main petroleum pipe P. (See discussion, page 329.)

The petroleum is transported from Baku in tanks; and in some cases wooden barges, which were not specially prepared for the purpose, are filled with petroleum. Thus a great quantity of water gets mixed up with the petroleum by leakage, &c. So long as the petroleum is cold, say below freezing point, the water does not easily separate from it. But whenever the petroleum is warmed up, say to 50° Fahr., the water separates very readily. On each tender-tank is therefore placed a water collector, as shown at W in Fig. 5, Plate 53, having a cock for letting the water off occasionally as it accumulates.

Each tender-tank is also fitted with a gauge-glass of 1 inch diameter, having a scale of inches graduated on a wooden frame that is used to stiffen the glass, which is over 4 feet long. By means of the gauge-glass, the engine-driver can see how the petroleum goes, each inch on the gauge being equivalent to so many poods or lbs.; the tanks being of rectangular form, their area is the same top and bottom. For a six-wheeled locomotive the capacity of the tank is $3\frac{1}{2}$ tons of oil,—a quantity sufficient for 250 miles, with a train of 480 tons gross, exclusive of engine and tender.

In charging the tender-tank with petroleum it is of great importance to have strainers of wire cloth in the manhole M, Fig. 5, Plate 53, of two different meshes, the outer one having openings say of $\frac{1}{4}$ inch, the inner say of $\frac{1}{8}$ inch; these strainers are occasionally taken out and cleaned. If care be taken to prevent any solid particles from entering with the petroleum, no fouling of the spray injector is likely to occur; and even if an obstruction should arise, the obstacle being of small size can easily be blown through by screwing back the steam cone in the spray injector, Fig. 17, Plate 57, far enough to let

the solid particles pass and be blown out into the fire-box by the steam. This expedient is easily resorted to even when running; and no more inconvenience arises than an extra puff of dense smoke for a moment, in consequence of the sudden admission of too much fuel.

Besides the two strainers in the manhole M of the petroleum tank on the tender, there should be another strainer inside the tank at the outlet valve V, as shown in Fig. 5, Plate 53, having a mesh of $\frac{1}{8}$ inch holes.

Driving of Locomotives.—In lighting up, certain precise rules have to be followed, in order to prevent explosion of any gas that may have accumulated in the fire-box. Such explosions do often take place in cases of negligence; but they amount simply to a puff of gas, driving smoke out through the ash-pan dampers, without any disagreeably loud report; this is all prevented by adhering to the following simple rules. First clear the spray-nozzle of water, by letting a small quantity of steam blow through, with the ash-pan doors open; at the same time start the blower in the chimney for a few seconds, and the gas, if any, will be immediately drawn up the chimney. Next place on the bottom of the combustion chamber a piece of cotton waste, or a handful of shavings, saturated with petroleum, and burning with a flame. Then by opening first the steam-valve of the spray injector, and next the petroleum nozzle gently, the very first spray of oil coming on the flaming waste immediately ignites without any explosion whatever; after which the quantity of fuel can be increased at pleasure. By looking at the top of the chimney, the supply of petroleum can be regulated by observing the smoke; the general rule is to allow a transparent light smoke to escape, thus showing that neither too much air is being admitted nor too little. The combustion is quite under the control of the driver, and the regulation can be so effected as to prevent smoke altogether.

While running, it is indispensable that the driver and fireman should act together, the latter having at his side of the engine the four handles for regulating the fire; namely the steam wheel and the petroleum wheel for the spray injector, and the two ashpan-door

handles in which there are notches for regulating the air admission. Each alteration in the position of the reversing lever or screw, as well as in the degree of opening of the steam regulator or the blast pipe,* requires a corresponding alteration of the fire. Generally the driver passes the word when he intends shutting off steam, so that the alteration in the firing can be effected before the steam is actually shut off; and in this way the regulation of the fire and that of the steam are virtually done together. All this care is necessary to prevent smoke, which is nothing less than a waste of fuel.

When, for instance, the train arrives at the top of a bank, which it has to go down with the brakes on, exactly at the moment of the driver shutting off the steam and shifting the reversing lever into full forward gear, the petroleum and steam are shut off from the spray-injector, the ashpan doors are closed, and if the incline be a long one, the revolving iron damper over the chimney top is moved into position, closing the chimney, though not hermetically. The accumulated heat is thereby retained in the fire-box; and the steam even rises in pressure, from the action of the accumulated heat alone. As soon as the train reaches the bottom of the incline and steam is again required, the first thing done is to uncover the chimney-top; then the steam is turned on to the spray injector, and next a small quantity of petroleum is admitted, but without opening the ashpan doors, a small fire being rendered possible by the entrance of air around the spray-injector as well as by possible leakage past the ashpan doors. The spray immediately on coming in contact with the hot chamber ignites without any audible explosion; and the ashpan doors are finally opened, when considerable power is required, or when the air otherwise admitted is not sufficient to support complete combustion.

On the spindle above the foot-plate, which regulates the supply of petroleum, is cut a double-threaded screw, having a brass nut and

* In all the locomotives on the Grazi and Tsaritsin Railway the blast orifice is variable, as is the case on nearly all Russian railways. With the use of petroleum as fuel it is now possible to have a fixed blast-orifice of large area, thus offering less resistance.

pointer D, Figs. 6 and 8, Plate 54. This pointer traverses a brass scale graduated from 0 to 20; so that during night-time, when it is not possible to distinguish between steam or smoke from the chimney-top, the driver regulates the petroleum by means of the scale. Besides this there is a sight-hole H in the fire-door; the door itself is always kept closed, and indeed is built up with brick and plated over, as in Figs. 4, 8, and 10, Plates 52 to 55. By looking at the fire through the sight-hole it can always be seen at night whether the fire is white or dusky; in fact with altogether inexperienced men it was found that after a few trips they could become quite expert in firing with petroleum. The better men contrive to burn less fuel than others, simply by greater care in attending to all the points essential to success.

At present one hundred locomotives are running with petroleum firing: thirteen of them are passenger engines, twenty-seven are eight-wheel coupled goods engines, and sixty are six-wheel coupled. As might be expected, several points have arisen which must be dealt with in order to ensure success. For instance, the distance ring R, Figs. 8 and 10, between the plates around the firing door, is apt to leak, in consequence of the intense heat driven against it and the absence of water circulation; it is therefore either protected by having the brick arch built up against it, or, better still, it is taken out altogether when the engines are in for repairs, and a flanged joint is substituted, similar to what is now used in the engines of the London and North Western Railway. This arrangement gives better results, and occasions no trouble whatever.

Storage of Petroleum.—The length of line now worked with petroleum is from Tsaritsin to Grazi, and also the branch line from the Volga to the Don, together making a total distance of 423 miles. There is a main iron reservoir for petroleum at each of the seven engine-sheds, namely at Tsaritsin, Archeda, Filonoff, Borisoglebsk, Burnack, Grazi, and Crootaya. Each reservoir is 66 feet internal diameter and 24 feet high, and when full holds about 2050 tons. The method of charging the reservoir, which stands a good way from the line and is situated at a convenient distance from

all dwelling houses and buildings, is as follows. On a siding specially prepared for the purpose are placed ten cistern-cars full of oil, the capacity of each being about 10 tons. From each of these cars a connection is made by a flexible india-rubber pipe to one of ten stand-pipes which project 1 foot above the ground line. Parallel with the rails is laid a main pipe, with which the ten stand-pipes are all connected, thus forming one general suction main. About the middle of the length of the main, which is laid underground and covered with sawdust or other non-conducting material, is fixed a Blake steam-pump. As soon as all the ten connections are made with the cistern-cars, the pump is set to work, and in about one hour the whole of the cars are discharged into the main reservoir, the time depending of course upon the capacity of the pump. All the pipes used are of malleable iron, lap-welded and of 5 inches internal diameter, having screwed coupling muffs for making the connections.

At each engine-shed, in addition to the main storage reservoir, there is a smaller distributing tank, shown in Fig. 18, Plate 58, which is erected at a sufficient height to supply the tenders, and very much resembles the ordinary water tanks. These distributing tanks are circular, $8\frac{1}{2}$ ft. diameter outside and 6 ft. high, and of $\frac{1}{4}$ inch plates; their inside mean area is calculated exactly, and a scale graduated in inches stands in the middle of the tank; a glass with scale is used outside in summer time. Each inch in height on the scale is converted into cubic feet, and then by means of a table is converted into Russian poods, according to the specific gravity at various temperatures. As it would be superfluous to graduate the table for each separate degree of temperature, the columns in the table show the weights for every eight degrees Réaumur, which is quite sufficient:—namely from 24° to 17°, from 16° to 9°, and so on, down to − 24°: the equivalent Fahrenheit range being from 86° down to − 22°. Suppose the filling of a tender-tank draws off a height of 27 inches from the distributing tank, at a temperature of say − 20° R., these figures are shown by the table to correspond with 200·61 poods = 7245 lbs. or 3·23 tons of petroleum. This arrangement does very well in practice; both the quantity and the

temperature are entered on the driver's fuel bill at the time of his taking in his supply.

Besides firing locomotives, which was the main problem on the Grazi and Tsaritsin Railway, the use of petroleum is equally economical in firing other boilers. At present a Galloway boiler having two furnaces is fired with petroleum at the Borisoglebsk shops. Drawings of the arrangement are shown in Figs. 13 to 15, Plate 56; the spray-injectors are of exactly the same dimensions as those used for the locomotives, but are without the worm and worm-wheel for regulation, a simple hand-wheel being used instead. The shop boiler at Tsaritsin also is now fitted with the same appliance, the fire-box being exactly of locomotive design. There is one case of a 10-horse pumping-engine on the banks of the Volga, where the boiler is horizontal and tubular, and is fired with petroleum under the cylindrical part. As it is there necessary to raise steam sometimes from cold water, the regenerator or fire-brick chamber is so arranged as to admit of wood firing to begin with. As soon as steam is got up to 10 or 15 lbs. pressure, the spray-injector is started to work, and no more wood firing is required. In this arrangement the air necessary for combustion is heated before coming in contact with the spray, by passing it round the outside of the regenerator, which has walls 4½ inches thick, through a narrow passage as shown, thus at the same time saving the regenerator from rapid destruction by the intense heat.

Gauging of Petroleum.—The qualities of the petroleum being very different, it is indispensable that each district engineer on the line should have a hydrometer and thermometer in his office, so as to test the specific gravity and temperature of the petroleum refuse supplied; for not only are there ten different grades of quality to deal with, but the specific gravity of each varies with its temperature, and has to be taken into account in reckoning with the drivers, who are paid a premium for saving fuel. Table I. appended shows the results of laboratory research in this direction, and is taken as a standard for guidance, especially for the petroleum refuse generally met with in commerce. The laboratory temperatures are Centigrade,

but Réaumur's thermometer is the one invariably used in Russia; Fahrenheit is added in the table for convenience. The heaviest petroleum refuse has a specific gravity of 0·921, or a weight of 57·412 lbs. per cubic foot when at freezing point, thus requiring a space of 39 cubic feet to contain a ton. The lightest at a temperature of 95° Fahr. has a specific gravity of 0·889, or a weight of 55·24 lbs. per cubic foot, requiring a space of 40½ cub. ft. to contain a ton. The specific gravity of the petroleum refuse delivered in December 1883, at a temperature of 8° to 9° C. (or 46° to 48° F.) was from 0·906 to 0·905, giving a weight of 56·3 lbs. per cubic foot.

Consumption of Petroleum Refuse.—Careful trials have been made to ascertain the mean consumption during continuous trips in winter and in summer; and also to determine the economy of petroleum refuse in comparison with anthracite, bituminous coal, and wood.

In Fig. 2, Plate 51, is shown the profile of the line where the experiments were made. Beginning at Tsaritsin the line rises at the rate of 1 in 125, which is also the ruling gradient, with very frequent curves of 300 sajenes = 2100 feet radius, as shown on the plan, Fig. 1. In reality the gradients are probably even steeper than 1 in 125, and the curves of even smaller radius than 2100 feet, those figures being taken from the original plans of the line when first made. As it is almost one continuous rise for about 10 miles from Tsaritsin station, without any level portions, it is necessary on this particular section to take five cars less than on any other; so that in summer the trains on this portion consist of twenty-five cars, or 400 tons gross, exclusive of engine and tender, whereas on all other parts of the line the trains contain thirty cars or 480 tons gross. The total distance from Tsaritsin on the Volga to Archeda, where engines are changed, is 97 English miles. Fully loaded trains run up from Tsaritsin; but in the return trips generally 60 per cent. of the cars are unloaded.

In Fig. 3, Plate 51, is shown the general design of the goods locomotives used in the trials. These engines were built by Borsig of Berlin, Schneider of Creusot, and the Russian Mechanical and Mining Company of St. Petersburg. Their main dimensions and

weights were about the same, as follows, all of them having six wheels coupled and 36 tons adhesive weight; as originally constructed they had ordinary fire-boxes for burning anthracite or wood.

Engine.—Cylinders $18\frac{1}{8}$ ins. diameter and 24 ins. stroke. Slide-valves, outside lap $1\frac{1}{16}$ inch, inside lap 3-32 inch, maximum travel $4\frac{9}{16}$ ins.; Stephenson link-motion. Boiler pressure 120 to 135 lbs. per sq. inch. Six wheels, all coupled, 4 ft. 3 ins. diameter on tread. Distance between centres of leading and middle wheels, 6 ft. $2\frac{3}{4}$ ins.; between middle and trailing, 4 ft. $9\frac{1}{4}$ ins.; total length of wheel-base, 11 ft. 0 in. Weight empty, on leading wheels, 11 tons; middle, $10\frac{1}{2}$ tons; trailing, $10\frac{1}{2}$ tons; total weight, 32 tons empty. Weight in running order, on leading wheels, 12 tons; middle, 12 tons; trailing, 12 tons; total weight, 36 tons in running order. Tubes, number 151; outside diameter, $2\frac{1}{8}$ ins.; length between tube-plates, 13 ft. $10\frac{1}{8}$ ins.; outside heating surface, 1166 sq. ft. Fire-box heating surface, 82 sq. ft. Total heating surface, 1248 sq. ft. Fire-grate area, 17 sq. ft. Mean boiler-pressure, $8\frac{1}{2}$ atmospheres. Tractive power = 65 per cent. of boiler pressure $\times \frac{(\text{cyl. diam.})^2 \times \text{stroke}}{\text{diameter of wheels}}$ $= 0 \cdot 65 \times 127\frac{1}{2} \times \frac{(18 \cdot 125)^2 \times 24}{51} = 5 \cdot 72$ tons. Ratio of tractive power to adhesion weight $= \frac{5 \cdot 72}{36 \cdot 00} = \frac{1}{6 \cdot 29}$.

Tender.—Contents; water, 312 cub. ft. or 1943 gals. or $8\frac{1}{2}$ tons; anthracite, 600 poods or 10 tons; or wood, $1\frac{1}{2}$ cub. sajene or 514 cub. ft. Weight empty, 10·8 tons; weight in running order, 29·3 tons. Six wheels.

Table II. appended shows the results of a continuous set of seventeen trips made with petroleum alone, for the purpose of arriving at a mean consumption per mile; and no doubt, had the drivers had an opportunity previous to these trials of becoming thoroughly acquainted with its use, the consumption would have been less than the mean here shown of 39·15 lbs. per train-mile. The severe frosts prevalent at the time of the trials are by no means an inconvenience for the use of petroleum; it is simply necessary to exercise more rigorous care in preventing cold air from getting

into the fire-box when the steam is shut off at stations or in running down hill. It is also indispensable to warm the petroleum at such periods of severe frost.

Table III. shows the results of comparative trials made in winter with different sorts of fuel, under exactly similar conditions as to type of engine, profile of line, and load of train. Two sets of comparative trials were made, both of them in winter. The three engines used were some of those built by Schneider. In comparison with anthracite, the economy in favour of petroleum refuse was 41 per cent. in weight and 55 per cent. in cost. With bituminous coal there was a difference of 49 per cent. in favour of petroleum as to weight, and 61 per cent. as to cost. As compared with wood, petroleum was 50 per cent. cheaper. At a speed of 14 miles an hour up an incline of 1 in 125 the steam pressure was easily kept up at 8 to $8\frac{1}{2}$ atm. with a No. 9 injector feeding the boiler all the time.

Table IV. gives a continuous set of nineteen trials made in summer with petroleum alone, under ordinary conditions of traffic, showing a mean consumption of 32·08 lbs. per train-mile, including lighting up. The mean evaporation per lb. of fuel was 11·35 lbs. of water from an initial temperature of about 55° Fahr.; the theoretical evaporative power of petroleum being 16·2 lbs. of water, the useful effect was therefore $\frac{11\cdot35}{16\cdot2} = 70$ per cent.

Table V. shows comparative tests made in summer with petroleum refuse versus bituminous coal and anthracite. As compared with bituminous coal, petroleum refuse shows an advantage of 56 per cent. in weight and 66 per cent. in cost; and in comparison with anthracite its economy is 52 per cent. in weight and 63 per cent. in cost. The mean speed in summer is 15 miles an hour.

Tables VI. and VII. show the monthly averages during the entire year 1883 of consumption and cost of fuel per train-mile in locomotives of the different classes, working main-line goods, mixed, and passenger trains. Table VI. is drawn out in the form of a diagram in Fig. 19, Plate 58, where the full lines represent coal consumption and the dotted lines petroleum; the pair of lines B B are from engines with six wheels coupled, working goods trains; and the

pair D D from engines with four wheels coupled, working passenger trains. These two pairs of lines show at a glance the difference in favour of petroleum. The mean result of the pair B B for the whole year is a coal consumption per train-mile of 69·80 lbs. as compared with 43·19 lbs. of petroleum, at a cost of 10·212 pence for coal and 5·495 pence for petroleum; being an advantage of 38 per cent. in weight and 46 per cent. in cost of petroleum refuse. From the pair of lines D D the mean result per train-mile is 39·38 lbs. of coal against 29·62 lbs. of petroleum, at a cost of 5·672 pence for coal and 3·808 pence for petroleum; being an advantage of 25 per cent. in weight and 33 per cent. in cost of petroleum refuse. The coal used is half of it bituminous and half anthracite; the latter is invariably from a top seam not very pure, and is called semi-anthracite, its evaporative power not being so high as that of the purer anthracite from the lower seams.

Table VIII. shows comparative trials with petroleum refuse and anthracite in passenger locomotives, giving an advantage of 36 per cent. to petroleum refuse in mean consumption per carriage-mile.

Table IX. shows comparative trials in goods engines with petroleum refuse, anthracite, and bituminous coal. The advantage in favour of petroleum in mean consumption per truck-mile is here 45 per cent. over anthracite and 57 per cent. over bituminous coal. In a subsequent trial an advantage of 57 per cent. over anthracite, and of 67 per cent. over bituminous coal, has been obtained in another of these same engines, having fore and aft ashpan doors, whereby the entering air was somewhat warmed prior to coming into contact with the gases in the combustion chamber; and the author considers that, with suitable arrangements for heating the air as highly as possible beforehand, the results already attained will ultimately be considerably surpassed.

In explanation of the apparently high consumption of fuel per mile, as shown by these Tables, it must be borne in mind that the line is a single one, having in many places 16 miles between stations, so that much time is lost in standing at stations, waiting to cross trains coming in the opposite direction, thus entailing a considerable extra consumption as compared with a double line. Moreover the

trains are heavy, as much as 720 tons gross load being taken by the eight-wheeled locomotives up inclines which, though not so steep as many in England, are very long at a stretch. Also, owing to the vast extent of the open plains, stretching as far as the eye can reach, the line is altogether unsheltered from the wind, which during winter and spring is sometimes strong enough to blow the men off their engine, were they not protected by doors to the cab and by railings all round.

Petroleum is further employed by the writer as an anti-incrustator in his stationary and locomotive boilers, and he finds it the best he ever used; it also prevents priming, except when used in too large a quantity. About 4 lbs. of petroleum are now being used for every 100 miles run, and the boilers are washed out every 600 miles.

In Figs. 9, 10, and 12, Plates 55 and 56, is shown the newest construction of the regenerative combustion chamber as now used. This arrangement gives excellent results, and has the advantage firstly that no side-doors are required to be cut in the ashpan, the original front and back doors being utilised. Secondly the air drawn in through the front ashpan door is passed up through a thin brick channel A thoroughly heated, whereby the air itself is heated to a certain extent before coming in contact with the products of combustion. Two cast-iron boxes B B are built into the brickwork, in order to let a small quantity of flame pass through them to that part of the tube-plate immediately underneath the tubes, thus utilising the whole of the heating surface.

The spray-injector, as shown in Fig. 10, is placed in the ashpan; whereas in the earlier arrangements it was fixed to the fire-box, and a connection was made by a hollow stay through the water space, Figs. 8 and 17. But on the eight-wheel coupled locomotives built by Kessler of Wurtemberg the ashpans are made very deep, thus admitting of the spray-injector being applied as here shown, which is more convenient and costs less than the arrangement with shallow ashpans.

From what the author has already observed with the eight-wheeled engines that he has altered for burning petroleum, he is satisfied the results are even better than with the six-wheeled locomotives having larger diameter of wheels. This he attributes firstly to the

larger extent of heating surface in proportion to tractive power in the eight-wheeled engines; and secondly to the greater frequency of the blast-beats with the smaller wheels.

Up to the present time the author has altered one hundred locomotives to burn petroleum; and from his own personal observations made on the foot-plate with considerable frost he is satisfied that no other fuel can compare with petroleum either for locomotives or for other purposes. In illustration of its safety in case of accident, a photograph is exhibited of an accident that occurred on the author's line on 30th December 1883, when a locomotive fired with petroleum ran down the side of an embankment, taking the train after it; no explosion or conflagration of any kind took place under such trying circumstances, thus affording satisfactory proof of the safety of the petroleum refuse in this mode of firing. The great facility for regulating and stopping the petroleum fire, combined with its cleanliness, is a great advantage for the regular working of the trains; and during the last fourteen years the author has never had more regular time kept, or greater freedom from stoppages and delays, than he now has with petroleum firing. This he has no doubt will have a great deal to do with lessening boiler and engine expenses in repairs and cleaning.

Another point of importance for countries where there are extensive steppes or prairies is that, as there are no sparks to fly from the chimneys and no clinkers to drop from the ashpans of the locomotives fired with petroleum, there are no prairie or steppe fires, such as are caused every summer by coal-burning locomotives. Moreover in Russia there are no roofing slates, but nearly all the engine sheds are roofed with Siberian sheet-iron, which is also used for sheathing the ceilings; this material does not last long when exposed to the sulphur evolved in coal-burning; but from petroleum fuel no trace of sulphur is found.

Although it is scarcely possible that petroleum firing will ever be of use for locomotives on the ordinary railways of coal-bearing England, yet the author is convinced that, even in such a country, its employment would be an enormous boon on underground lines.

TABLE I.—*Petroleum Refuse.*

Specific Gravity and Weight per cubic foot, at various temperatures.

Water = 1·0000 specific gravity, at 17½° Cent. = 63½° Fahr.

Temperature.			Specific Gravity.	Weight in lbs. per cubic foot.
Centigrade.	Réaumur.	Fahrenheit.		
0	0·0	32·0	0·9110	56·61
1	0·8	33·8	0·9103	56·55
2	1·6	35·6	0·9097	56·50
3	2·4	37·4	0·9091	
4	3·2	39·2	0·9085	56·42
5	4·0	41·0	0·9078	56·36
6	4·8	42·8	0·9072	
7	5·6	44·6	0·9066	56·30
8	6·4	46·4	0·9060	
9	7·2	48·2	0·9053	56·20
10	8·0	50·0	0·9047	56·14
11	8·8	51·8	0·9041	
12	9·6	53·6	0·9034	56·11
13	10·4	55·4	0·9028	56·05
14	11·2	57·2	0·9022	
15	12·0	59·0	0·9016	55·99
16	12·8	60·8	0·9009	55·92
17	13·6	62·6	0·9003	
18	14·4	64·4	0·8997	55·84
19	15·2	66·2	0·8991	
20	16·0	68·0	0·8984	55·81
21	16·8	69·8	0·8978	55·74
22	17·6	71·6	0·8972	
23	18·4	73·4	0·8965	55·68
24	19·2	75·2	0·8959	55·62
25	20·0	77·0	0·8953	
26	20·8	78·8	0·8947	55·55
27	21·6	80·6	0·8940	
28	22·4	82·4	0·8934	55·48
29	23·2	84·2	0·8928	55·43
30	24·0	86·0	0·8922	
31	24·8	87·8	0·8915	55·37
32	25·6	89·6	0·8909	55·30
33	26·4	91·4	0 8903	
34	27·2	93·2	0·8896	55·24
35	28·0	95·0	0·8890	

Equivalent Russian and English Measures.

1 sajene = 7 feet. 500 sajenes = 1 verst = 0·6629 mile.

1 pound = 0·90285 lb. 40 pounds = 1 pood = 36·114 lbs. 62·0257 poods = 1 ton.

1 copeck = 0·24 penny. 100 copecks = 1 rouble = 24 pence.

TABLE II.—*Petroleum Refuse.*

Continuous Trials in Seventeen Trips on different sections of Grazi and Tsaritsin Railway, to ascertain Mean Consumption in Winter time.

Date. 1883.	Section of Line.	Locomotives.	Train.	Train alone. Number of loaded Cars.	Train alone. Gross Load.	Distance run.		Car-Miles.	Petroleum Refuse consumed, including lighting up.	Atmospheric Temperature.		Weather.
				No.	Tons.	Versts.	Miles.		Tons.	Réaum.	Fahr.	
Jan. 18	Borisoglebsk to Burnack, and back	23	24–23	24	384	144	95	2280	1·739	$-15°$	$-2°$	Side wind.
19	Ditto, ditto. . . .	23	28–25	24·33	389·3	144	95	2303	1·854	-8 to -10	14 to 9½	Strong side wind.
21	Borisoglebsk to Filonoff	23	29	26	416	104	69	1794	1·116	-5	21	Calm.
22	Filonoff to Archeda .	23	21	23·4	374·4	118	78	1825	1·4401	-7	16	Light side wind.
23–4	Archeda to Tsaritsin, and back. . . .	23	27–32	24	384	292	193	4632	3·581	-17 to -18	-6 to $-8\frac{1}{2}$	Strong side wind.
Feb. 13	Archeda to Tsaritsin .	8	27	14	224	146	97	1358	1·326	-4	23	Light wind.
15	Borisoglebsk to Tsaritsin. . . .	7	27–31	22	352	368	254	5588	4·653	-6	18½	Light side wind.
23	Ditto	35	27–31	22	352	368	254	5588	4·657	-10 to -15	9½ to -2	Strong side wind.
March 8	Archeda to Tsaritsin .	8	21	14	224	146	97	1358	1·394	$+2$	36½	Calm.
11	Tsaritsin to Archeda, and back. . . .	14	26–31	24·43	390·9	292	193	4698	3·2205	-7	16	Side wind.
14	Archeda to Ilovla. .	40	30	21	336	58	38	798	0·5901	-11	7	Calm.
Means and Totals				21·74	347·9	2180	1463	32222	25·5707			

Mean Consumption of Petroleum Refuse = **39·15 lbs.** per train-mile, including lighting up.
Mean Cost of Petroleum Refuse, at 21s. per ton, = **4·4 pence** per train-mile.

TABLE III.—*Petroleum Refuse.*

Comparative Trials with Petroleum, Anthracite, Bituminous Coal, and Wood, between Archeda and Tsaritsin on Grazi and Tsaritsin Railway, in Winter time. (*Figs.* 1 *and* 2, *Plate* 51.)

Date. 1883.	Locomotive.	Train.	Train alone.		Distance run.	Car-Miles.	Fuel.	Consumption, including lighting up.		Cost of Fuel per Train-Mile.	Atmospheric Temperature, and Weather.
			Number of loaded Cars.	Gross Load.				Total.	Per Train-Mile.		
			No.	Tons.	Miles.					Pence.	
Feb. 8	8	32–23 32–23	25	400	388	9700	Anthracite	31779 lbs.	81·90 lbs.	11·957	– 17° to – 18° Réau. equivalent to
	14	24–21 24–21	25	400	388	9700	Bituminous Coal	37557·5 lbs.	96·53 lbs.	14·093	– 6° to – $8\frac{1}{2}$° Fahr.
	7	26–29	25	400	194	4850	*Petroleum Refuse*	9462 lbs.	48·77 lbs.	5·487	Strong side wind.
Mar. 6	24	32–23	25	400	194	4850	Anthracite	12639·5 lbs.	65·15 lbs.	9·512	– 5° to – 9° Réau.
	21	24–21	25	400	194	4850	Wood, in billets	1071·8 cub. ft.	5·52 c. ft.	8·5	equivalent to 21° to 12° Fahr.
	23	26–27	25	400	194	4850	*Petroleum Refuse*	7223 lbs.	37·23 lbs.	4·188	Light side wind.

Prices of Fuel.—Petroleum Refuse, 21*s.* per ton. Anthracite, and Bituminous Coal, 27*s.* 3*d.* per ton.
Wood, in billets, 42*s.* per cubic sajene = 343 cubic feet; equivalent to 1·47 penny per cubic foot.

Dimensions of Locomotives.—Cylinders $18\frac{1}{8}$ ins. diam. and 24 ins. stroke. Wheels 4 ft. 3 ins. diam. Total heating surface 1248 sq. ft.
Total adhesion weight 36 tons. Boiler pressure 8 to 9 atm.

TABLE IV.—*Petroleum Refuse.*

Continuous Trials in Nineteen Trips between Archeda and Tsaritsin on Grazi and Tsaritsin Railway, to ascertain Mean Consumption in Summer time. (*Figs.* 1 *and* 2, *Plate* 51.)

Date. 1883. June.	Locomotive.	Train.	Number of loaded Cars. From Tsaritsin to Gorodisha, 14 miles.	From Gorodisha to Archeda, 83 miles.	From Archeda to Tsaritsin, 97 miles.	Mean for total distance.	Distance run.	Petroleum Refuse consumed, including lighting up.	Mean Results, including lighting up.
			No.	No.	No.	No.	Miles.	Ton.	
8	15	38	25	30	..	29	97	1·715	**Mean Consumption**
..	29	28	25	30	..	29	97	1·847	of Petroleum Refuse,
9	15	25	..	..	30	30	97	1·219	**32·08 lbs.** per train-mile.
..	29	27	..	..	30	30	97	1·128	
..	57	30	25	30	..	29	97	1·704	
..	23	32	25	30	..	30	97	1·456	**Mean Cost**
10	15	38–25	25	30	30	29	199	2·957	of Petroleum Refuse,
11	29	31	..	..	31	31	97	1·256	at 21*s.* per ton,
..	23	21	..	..	30	30	97	1·149	**3·61 pence** per train-mile.
10	29	30	25	30	..	29	97	1·453	
11	23	12–21	25	30	..	29½	194	2·701	
12	29	26–27	25	30	30	29½	194	2·828	**Mean Evaporation,**
17	57	34	12	30	..	27½	97	1·419	**11·35 lbs.** of Water
21	14	36	10	30	..	27	97	1·399	per lb. of Petroleum Refuse.
22	14	11	..	..	30	30	97	1·138	
..	57	21	..	..	30	30	97	1·102	
Mean and Totals						29·3	1848	26·471	

TABLE V.—*Petroleum Refuse.*

Comparative Trials with Petroleum, Anthracite, and Bituminous Coal, between Archeda and Tsaritsin on Grazi and Tsaritsin Railway, in Summer time. (Figs. 1 and 2, Plate 51.)

Date. 1883. July.	Locomotive.	Train.	Train alone. Number of loaded Cars.	Train alone. Gross Load.	Train-Miles.	Fuel.	Consumption, including lighting up. Total.	Consumption, including lighting up. Per Train-Mile.	Cost of Fuel per Train-Mile.
			No.	Tons.			Lbs.	Lbs.	Pence.
13	37	.....	30	480	194	Bituminous Coal	14084·07	72·598	10·599
	14	.....	30	480	194	*Petroleum Refuse*	6175·325	31·831	3·581
25	32	31–34	30	480	194	Anthracite	12781·002	65·897	9·621
	57	27–12	30	480	194	*Petroleum Refuse*	6103·097	31·459	3·539

Prices of Fuel.—Petroleum Refuse, 21*s.* per ton. Anthracite, and Bituminous Coal, 27*s.* 3*d.* per ton.

TABLE VI.—*Consumption of Fuel per Train-Mile.*

Comparative Monthly Averages during 1883 with Coal and Petroleum Refuse in Locomotives working main-line trains on Grazi and Tsaritsin Railway.

See Fig. 19, Plate 58.		Fuel.	Monthly Averages of Consumption per Train-Mile.												Mean.
Locomotives.	Trains.		Jan.	Feb.	Mar.	Apl.	May.	June.	July.	Aug.	Sep.	Oct.	Nov.	Dec.	
			Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Eight wheels coupled	Goods ... A	Coal*	98·06	108·96	100·79	76·27	76·27	79·00	74·91	73·55	79·00	85·81	98·06	95·34	87·17
Six wheels coupled ...	Goods ... B	Coal*	73·55	77·63	70·82	64·01	55·84	61·29	54·48	55·84	65·38	80·36	92·62	85·81	69·80
	Goods ... B	*Petroleum Refuse*	**53·12**	**54·48**	**46·31**	**42·22**	**34·05**	**35·41**	**31·33**	**36·10**	**40·86**	**39·50**	**50·39**	**54·48**	**43·19**
Four wheels coupled	Mixed ... C	Coal*	51·76	76·27	43·58	34·05	36·77	35·41	42·22	49·03	51·76	40·86	49·03	58·57	47·44
Four wheels coupled	Pass. ... D	Coal*	40·86	49·03	46·31	36·77	34·05	32·69	31·33	32·69	36·77	39·50	42·22	50·39	39·38
	Pass. ... D	*Petroleum Refuse*	...	...	...	...	...	...	...	...	**20·43**	**31·33**	**32·69**	**34·05**	**29·62**

* Of the Coal consumed, 49 per cent. was Anthracite, and 51 per cent. was Bituminous coal. The anthracite used is from a top seam not very pure, and is called semi-anthracite.

TABLE VII.—*Cost of Fuel per Train-Mile.*

Comparative Monthly Averages during 1883 with Coal and Petroleum Refuse in Locomotives working main-line trains on Grazi and Tsaritsin Railway.

Locomotives.	Trains.	Fuel.	Jan.	Feb.	Mar.	Apl.	May.	June.	July.	Aug.	Sep.	Oct.	Nov.	Dec.	Mean.
			Monthly Averages of Cost per Train-Mile.												
			Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	Pence.
Eight wheels coupled	Goods	Coal *	13·495	15·635	14·346	11·226	11·319	11·704	11·186	10·925	11·552	12·471	14·600	13·930	12·699
Six wheels coupled ...	Goods ...	Coal *	10·520	11·099	9·897	9·405	8·387	9·317	8·217	8·279	9·694	11·776	13·647	12·344	10·212
		Petroleum Refuse	**7·294**	**7·602**	**6·158**	**4·973**	**4·040**	**4·163**	**3·617**	**4·170**	**4·948**	**4·771**	**6·817**	**7·356**	**5·495**
Four wheels coupled	Mixed......	Coal *	7·353	10·973	6·672	4·934	5·466	4·988	6·267	7·269	11·215	5·908	7·102	8·652	6·932
Four wheels coupled	Passenger	Coal *	6·070	7·023	6·602	5·144	4·829	4·670	4·445	4·819	5·165	5·633	6·111	7·580	5·672
		Petroleum Refuse	...	...	...	...	...	...	...	...	**2·411**	**5·611**	**4·366**	**4·634**	**3·808**

* Of the Coal consumed, 49 per cent. was Anthracite, and 51 per cent. was Bituminous coal. The anthracite used is from a top seam not very pure, and is called semi-anthracite. Mean Prices of Fuel.—Petroleum Refuse, 23*s.* 4*d.* per ton. Coal, 27*s.* per ton.

TABLE VIII.—*Petroleum Refuse.*

Comparative Trials with Petroleum and Anthracite, between Grazi and Borisoglebsk on Grazi and Tsaritsin Railway.

Date. 1884. June.	Locomotive.	Train.	Train alone. Mean Number of Carriages.	Train alone. Gross Load.	Distance run. Train-Miles.	Distance run. Carriage-Miles.	Fuel.	Consumption, including lighting up. Total.	Per Train-Mile.	Per Carriage-Mile.	Mean per Carriage-Mile.	Weather.
			No.	Tons.				Lbs.	Lbs.	Lbs.	Lbs.	
6 – 7	109	4-3	15	240	264	3960	Anthracite	11560·5	43·79	2·92	3·118	Good.
8 – 9	109	4-3	13	208	264	3432	Anthracite	11379	43·101	3·316		
7 – 8	116	4-3	13	208	264	3432	*Petroleum Refuse*	6720	25·45	1·957	1·983	Good.
9–10	116	4-3	$12\frac{1}{2}$	200	264	3300	*Petroleum Refuse*	6632·5	25·124	2·01		

Dimensions of Passenger Locomotives (Borsig's).—Cylinders, $17\frac{3}{8}$ ins. diam. and 22 ins. stroke. Driving wheels, four coupled, 5 ft. 3 ins. diam. Total weight, 32 tons. Adhesion weight, 25 tons. Boiler pressure, $8\frac{1}{2}$ atm. Carriages six-wheeled, each 16 tons mean gross weight. Speed, 24 to 26 miles per hour. Maximum gradient, 1 in 125.

TABLE IX.—*Petroleum Refuse.*

Comparative Trials with Petroleum, Anthracite, and Bituminous Coal, between Borisoglebsk and Filonoff on Grazi and Tsaritsin Railway.

Date. 1884.	Locomotive.	Train.	Train alone.		Distance run.		Fuel.	Consumption, including lighting up. (*including *twice* lighting up.*)				Weather.
			Mean Number of Trucks.	Gross Load.	Train-Miles.	Truck-Miles.		Total.	Per Train-Mile.	Per Truck-Mile.	Mean per Truck-Mile.	
			No.	Tons.				Lbs.	Lbs.	Lbs.	Lbs.	
May. 20–21	147	31-28	43	688	136½	5870	Anthracite...........	9063	66·40	1·544	1·907	Wind favourable to train.
21–22	147	21–30	35	560	136½	4778	Anthracite...........	10841·5	79·43	2·27		Strong side wind.
23–24	147	31–30	38	608	136½	5187	Bituminous Coal......	12638	92·60	2·436	2·436	Calm.
20–21	141	26–27	45	720	136½	6143	*Petroleum Refuse......*	6274	45·90	1·02	1·046	Strong side wind.
22–23	139	27–28	41	656	136½	5597	*Petroleum Refuse......*	5524	40·46	0·9868		Calm.
23–24	138	21–30	42	672	136½	5733	*Petroleum Refuse......*	6151	45·06	1·0728		Calm.
26	137	25–34	45	720	136½	6143	*Petroleum Refuse......*	6787	49·72	1·105		Strong side wind.
June. 26–27	143	31–28	44	704	136½	6006	*Petroleum Refuse......*	*4841	*35·46	0·806*	*0·806	Calm.

Dimensions of Goods Locomotives (Kessler's).—Cylinders, 19¾ ins. diam. and 25⅜ ins. stroke. Wheels, eight coupled, 3 ft. 11¼ ins. diam. Total heating surface, 1938 sq. ft. Total adhesion weight, 46 tons. Tractive force, 18045 lbs. = 8·056 tons. Boiler pressure, 9 atm. Trucks each 16 tons gross weight. Speed, 14 miles per hour. Maximum gradient, 1 in 125.

Discussion.

Mr. Joseph Tomlinson remarked that this paper was written almost entirely from a locomotive superintendent's point of view; and to himself therefore it was a very interesting one, as showing that nature had provided for the wants of different countries in very different ways. In the south-eastern portion of Russia, to which the paper referred, there were large quantities of petroleum, but no coal; hence the results given in the paper as to the high cost per train-mile of fuel in the shape of anthracite and other coal. But he could not help thinking that there must be some points which required clearing up in the apparent discrepancies with reference to the proportions of water and fuel. Welsh coal had a theoretical evaporative value of 14 lbs. of water per lb. of fuel, and in page 274 of the paper petroleum refuse was credited with a theoretical evaporation of 16 lbs. of water; yet it was made out that the evaporative value of petroleum refuse was from 63 to 75 per cent. higher than that of anthracite, weight for weight; and therefore he thought there must be some discrepancy that wanted clearing up. Judging from the experience of burning petroleum in lamps in England, he had no doubt good results could be obtained from it; the lamps were almost entirely free from smoke; and therefore, with proper provision for the admission of air and petroleum refuse into the fire, he did not see why a good result should not be produced, doing away with the clouds of smoke sometimes seen from engines in England. It struck him as rather extraordinary that, as the author had now had so long experience, he had not yet departed more from the ordinary form of locomotive boiler; for it would be observed that he had had to make shifts in some portions of his engines by closing up doors, which, if the engines had been originally made for burning petroleum, need not have been there at all. But possibly that was a point which would be put right hereafter. The method of arranging the supply seemed to be all that could be desired; and the method of getting rid, by opening the spray nozzle, of the small particles of dirt which would naturally be met with in fuel of that kind, was very ingenious. The author deserved their

(Mr. Joseph Tomlinson.)
thanks, he thought, for the detailed and careful information he had given.

But on the Underground Railway, with which he was himself connected, he was afraid he should get into difficulty if he were to attempt to import petroleum for the sake of getting rid of the smoke in London. London was a peculiar place; the authorities would not allow anything to be stored that was thought at all inflammable below a certain temperature; and in this respect the use of petroleum on any extensive scale would involve a very serious difficulty. Another difficulty on the Underground Railway would be one that they were already subject to in burning coal. The engines worked so long in the tunnels that a driver could not see his chimney until he got into a station. Sometimes a train might be seen on the Underground Railway coming into a station very quickly: the fireman had perhaps put a little too much fire on, and the engine was making smoke on entering the station. So long as the engines worked in short tunnels and in the open air with the South Wales coal they were now using, it was the rarest thing to see smoke coming out of the chimneys at all; indeed the chimneys of most of the engines now working on the Underground Railway were still as clean as when they first left the shop. All that was found, in the absence of smoke, was a small refuse of almost impalpable powder in the shape of unconsumed carbon, which was cleaned out of the smoke-box once a week.

Mr. William Boyd had fitted five screw-steamers trading on the Caspian Sea with arrangements for burning petroleum refuse; and in Figs. 24 to 27, Plate 60, was shown the mode in which the apparatus employed had been fitted to the ordinary marine boilers in those vessels. In the front view of the boiler, Figs. 24 and 26, the supply pipe P brought the petroleum refuse from two tanks situated at the sides of the ship, the bottom of the tanks being placed at such a height that the refuse always gravitated towards the apparatus placed in front of the boiler. The vertical pipe S supplied the steam from the boiler. The brass trunk T leading to each furnace was divided all along its length by a horizontal partition; the

petroleum came in along the top channel, and the steam along the bottom, the supply of each being regulated by the cocks CC. The two orifices through which the jets of petroleum and steam issued into the furnace were inclined towards each other at an angle of about 45°, the combined jet shooting into the furnace in the manner shown in Fig. 25. This arrangement was simpler than the spray nozzle shown in Fig. 17, Plate 57, being more like the tyre-heating fire shown in Fig. 22, Plate 59. The mass of black stuff shown on the fire-bars in Fig. 25, Plate 60, was intended to represent cotton-waste or wood and shavings, saturated with oil, and set alight, in the same way as described in the paper for starting the firing in locomotives. The steam and petroleum were then admitted together gradually, until the whole spray caught fire and the flame came through the boiler tubes. From a marine engineering point of view, a peculiarity in the later of the five steamers so fired lay in the unusually great length of the boiler tubes in proportion to their diameter, the length having been materially increased as the result of experience: for whereas in the first steamer the boilers had tubes $3\frac{1}{4}$ ins. diameter and only 7 ft. long, the last one made had tubes $2\frac{3}{4}$ ins. diameter and 9 ft. long, the boiler being 12 ft. long over all. Some of the steamers had twin screws, and others had single engines, indicating from 200 to 400 HP.

It was a matter of very great regret that the author was not able to be present, because several questions might have been asked, the answers to which might have conveyed very interesting information. The price given in the paper of 21*s.* per ton for petroleum refuse was much higher than that given in the reports which the engineers sent out by himself had brought home from the Caspian Sea, where the stuff was so cheap that the steamers might almost be paid something for taking it on board. The cost of the material would of course affect very greatly the nature of any comparison with other fuel. As far as he had been able to gather, in default of any more accurate information, the consumption was something like $2\frac{1}{2}$ lbs. of petroleum refuse per indicated HP. per hour in small engines indicating 300 or 400 HP. That of course was not a very wonderful result; but the reports brought home to him showed that the stuff was very

(Mr. William Boyd.)
wastefully used, because it was thought from its being so cheap that it did not much matter whether the engines burned $2\frac{1}{2}$ lbs. or only $1\frac{1}{2}$ lb.

One point in the paper which struck him as very noticeable was that there was so large a difference between the consumption per train-mile in winter and that in summer. Under date of 8th Feb. 1883 it appeared from Table III. that the consumption of petroleum refuse was $48\frac{3}{4}$ lbs. per train-mile, and on 6th March $37\frac{1}{4}$ lbs.; while in Table IV., under date of 8th to 22nd June, being the middle of summer, there was a mean consumption of 32 lbs. per train-mile, which corresponded very closely with the consumption shown in Table V. for July. So that the consumption was increased something like 50 per cent. in the winter time, which he supposed was only what might be expected; but this point was one that it might be of considerable interest to hear something more about.

Reference had been made in the paper to the rapidity of raising steam, and also to the high temperature obtained with petroleum firing. Information in his own possession showed that steam could be raised very rapidly indeed; but of course in a marine boiler that was rather a dangerous thing to do very often. He had heard of an instance of steam being got up in rather less than an hour, the boiler containing 1800 square feet of heating surface; but he did not think such a thing should be attempted often. With the ordinary working of the marine boilers which he had described, fired with petroleum, he had not heard of any trouble, notwithstanding their long tubes of unusually small diameter; and he believed the steamers were still working satisfactorily.

Mr. G. B. Rennie considered the present paper was full of interest to the Institution, although the plans adopted for burning liquid fuel did not seem to himself to vary very much from what had been tried many years previously. About fourteen or fifteen years ago his own firm had tried it in a small boiler with an apparatus very similar to that described by Mr. Boyd, but somewhat more simple in construction. They then tried it for a month in their own shop

boiler, firing for a month with coal and a month with petroleum; and at the end of the experiment they certainly found that at the price they then paid for the petroleum there was an economy, the petroleum not costing so much for the month's firing as the coal did; but after a little time they found that the petroleum increased so much in value that they did not continue to use it. In the south east of Russia, at Baku on the Caspian Sea, in the valleys of the rivers Euphrates and Tigris, and at other places in that part of the world, there was an enormous quantity of petroleum fuel to be got for merely the cost of pumping it. Shortly after the time of their own experiments, his firm were supplying some engines for vessels navigating the Tigris and the Euphrates, and it was thought advisable that the ordinary marine boilers in these vessels, working at about 30 lbs. steam pressure and having their furnaces fitted with fire-bars in the usual way, should also be furnished with spray injectors for burning petroleum. The two boilers in each vessel were usually worked one with petroleum and the other with coal, because it was found there was occasionally a difficulty in getting the petroleum sufficiently pure, and the spray injectors then got clogged up. Notwithstanding the petroleum being strained by passing through felt and other sieves, there was always some dirt coming through in it, and the pipes used to get choked up, and the firing had to be stopped in order to clear them. Nevertheless the use of petroleum was continued for some time; and the economy in weight, when firing only one boiler with petroleum and the other with coal, amounted to 20 per cent., which would of course have been 40 per cent. if both boilers had been fired with petroleum. The economy in cost was considerable with this saving in weight, because the oil was cheap and the coal dear. Eventually however the use of petroleum was abandoned, because a difficulty was found in getting it sufficiently pure; the Arabs who sold it loaded it with all sorts of rubbish. He was glad to say that Mr. Tartt, the engineer superintendent of those steamers, was present, who was more familiar with the details of the working, and would be able to give them the results of his practical experience.

Mr. William Tartt, having recently returned from Baghdad, narrated the trials he had conducted with petroleum in Arabia. In 1869, new boilers having to be supplied to the Euphrates and Tigris Steam Navigation Company's vessel "City of London," it was thought advisable, as petroleum was plentiful in Arabia, to have them fitted up for trying its practicability. They were accordingly fitted up by Messrs. J. and G. Rennie to their own design, and sent out to Baghdad. The supply tank for petroleum was fixed on the upper deck of the vessel, and the spray pipe with its internal steam blow-pipe was passed through a plate fixed over the top of the furnace doors, the rounded top of the doors being cut off for that purpose. Petroleum was collected at three different parts of Arabia: at Hit, on the river Euphrates; at Ker-kook, some distance from the banks of the Tigris; and at Men-dil-ey, on the river Dey-el-ah. At the time of the trial petroleum could be had at Baghdad in small quantities only, and that mostly dirty. He collected it as he could, in order to make a trial; and was fortunate enough to procure it fairly good at first, and had then little or no trouble in getting it to burn. But after having been supplied once or twice by the same merchant, it was sure to be mixed with dirt, and could only be worked with great difficulty, owing to the spray pipe continually choking up. He would then change his merchant, but with the same results. It was always passed through strainers; but these would not arrest the dirt which had been mixed with it in order to make it weigh heavy. Hair and such like matter was also collected from it. One of the firemen, seeing the trouble that was experienced in getting the article pure, asked to be allowed to go to Ker-kook, his native place, in order to collect some. After some consideration he was allowed to go, and was empowered to purchase what skins he might require, and when full to send them to the bank of the river as best he could; there was no ordinary conveyance to take them. When the skins were collected on the bank of the river, a raft was made of inflated skins, with reeds in bunches secured to them; and the petroleum skins were placed on the top, and so brought down the river to Baghdad. This supply was found on trial to be very good; but it was very expensive, entailing the purchase of skins, cost of

carriage, &c., and black mail to be given to the various sheiks: besides which the Turkish authorities, after knowing what was its purpose, came down heavily for customs' dues, in order to crush it out of use. However the supplies received from Ker-kook and Men-dil-ey proved to his satisfaction that petroleum could be used as fuel, and that the cost and uncertainty of the necessary supply formed the only difficulty to be overcome.

The first trial was made on 30th January 1870. There were on board 3820 okes = 4·775 tons of petroleum (800 okes = 1 ton), and on that occasion both boilers were worked with it. Steam was first raised in the usual manner; then the fires were drawn, and bricks laid on the bars, as close as possible on the back part, and covered over with ashes. On the front part of the bars the bricks were not laid so close, in order that air might pass through them; and the doors of the furnaces were also full of holes. A fire was laid on the bricks about the middle of the furnace length, where the petroleum could best be blown upon it. First the chimney blast was turned on from the main steam-pipe, when the fire soon brightened up. The steam blow-pipe was then opened, and the petroleum turned on in such a way as appeared best, so that a bright flame could be seen. Very black smoke was emitted from the funnel, and a strong smell of petroleum was to be traced behind. The consumption for six hours was 1·100 ton, or 411 lbs. per hour. A trial was then made with coal for six hours, and the result was a consumption of 1·825 ton, or 681 lbs. per hour.

On 3rd March 1870 he took on board 3694 okes = 4·617 tons of petroleum. Steam was raised as usual in both boilers; but the fires were drawn from under the port boiler only, as the starboard boiler was to be fired with coal, and the port boiler with the liquid fuel. Previously to lighting the fires under the port boiler, he had had a second bridge of bricks built in each furnace a foot in advance of the usual fire-bridge, and carried up to the crown of the furnace, holes being left between all the bricks for the flame to pass through. After the fires were drawn, the bars were covered with bricks as formerly, and the fire laid on again. Bricks were then thrown in roughly at the back of the fire; and the chimney blast, the steam

(Mr. William Tartt.)
blow-pipe, and the petroleum feed were turned on, as in the former trial. At starting, and until the bricks became red-hot, there was both smoke and smell, but not quite so bad as in the first trial. When the bricks got red-hot, a beautiful white flame was the result, and steam was kept up with ease to the required pressure of 25 lbs. This trial he considered very satisfactory. The 4·617 tons of petroleum were consumed under the one boiler in 35½ hours, or at the rate of 291 lbs. per hour. The starboard boiler fired with coal needed only very easy firing, as the petroleum appeared to be doing the greater amount of work; it consumed 4·050 tons of coal, or at the rate of 255 lbs. per hour. The total consumption of coal and petroleum together amounted to 546 lbs. per hour, as against 681 lbs. of coal per hour in the trial in January.

On 9th April 1870 he took on board 3315 okes = 4·144 tons of petroleum; but it was so bad that it was with difficulty it could be used at all, and no account was therefore kept of it. He then changed to another merchant, who supplied 943 okes = 1·179 ton as a trial: this burnt well, and he ordered a supply. On 14th May he was supplied with 3214 okes = 4·018 tons, which proved as bad as any he had had, or worse; and 496 okes were returned on the merchant's hands. It was after these trials that the fireman was sent to Ker-kook, as previously mentioned; and although the results obtained from the supply thus procured were very good, he regretted that the expense had proved so great that the further use of petroleum had been discontinued.

Mr. T. R. Crampton considered this paper a very valuable one, not only from the important results obtained, but also because it brought so clearly before the Institution the fact that petroleum could be so successfully used under favourable circumstances. Its success of course depended simply upon its relative cost and heating value. Many years ago petroleum oil had been credited with a theoretical evaporative value of about 18 lbs. of water per lb. of oil, as against 14 lbs. for coal; consequently to make them equally useful economically there must be that proportion of price between them. Some fourteen or fifteen years ago he had had occasion to discuss the

question with the government authorities who were at that time making experiments on the use of liquid fuel; and he had told them it was useless to attempt to go on at the price. It would pay very well just then; but all the supply that could be got was no more than could be brought by one large steamer, and therefore, as soon as ever any considerable quantity was wanted, up would go the price: so that it would be useless to carry on the experiments under those circumstances. The way in which the petroleum refuse was being burnt in the locomotives described in the paper seemed to him a capital one, and he thought it could not very well be better; but in all these cases he thought the air also should be absolutely injected with the steam and oil, and mixed with them in the exact proportion required for perfect combustion. According to the evidence of what was being done, there were only $12\frac{1}{4}$ lbs. of water actually evaporated per lb. of petroleum, although its theoretical evaporative power was 16 lbs. Certainly with a material like that, which was easily mixed with air, and in this respect was not like coal which was difficult so to mix, a duty of at least 80 or 85 per cent. ought to be got, simply by properly mixing it; and there ought not to be a doubt about complete absence of smoke. It had been remarked by previous speakers that sometimes a great deal of smoke had been made in burning petroleum; but there was no necessity for this if the air was properly mixed with it. With regard to what Mr. Tartt had maintained about the firing of his boilers, there would have been no necessity to light up the fire beforehand if he had simply put the ignited coal on the bars and had blown the air upon it alone; then without having any open fire-bars the fire could be got up very well. He had done this himself many times under those conditions, and there was no difficulty in it.

He should like to know what was the temperature in the smoke-box when burning petroleum, as it could not be known whether the boilers were adapted for the purpose unless the temperature going away from the ends of the tubes into the chimney was known. In the locomotive boiler shown in the drawings the temperature he considered ought to be very much lower in the smoke-box than when burning coal; but nothing was stated about this. His own

(Mr. T. R. Crampton.)

impression was that a great deal of heat must be lost, and that perhaps as much as 700° or 800° F. went up the chimney; if so, that would account for only 12¼ lbs. of water being evaporated per lb. of petroleum. From his own experience he was perfectly satisfied that petroleum could be used quite practically and quite economically, provided the price was not too high.

Mr. F. C. Marshall, having fitted the boilers of one vessel for the use of petroleum fuel, thought it might be of interest that he should confirm Mr. Boyd's remarks, and show how some points had been dealt with by himself. The mode of supplying the petroleum was very much after the fashion shown by Mr. Boyd in Figs. 24 to 27, Plate 60, only that it was done through two separate pipes pointing towards each other. As already remarked, it was found necessary that the boilers should be made of greater length than usual, on account of the great length of flame that was obtained from the petroleum oil. In his own case the furnaces and tubes were made longer than those spoken of by Mr. Boyd. The tubes were 2½ ins. diameter and 10 ft. long, and even then the flame was found to come out of their further ends, the heat not having been fully absorbed. This he attributed to some extent to the want of air, to which Mr. Crampton had so properly called attention: in fact in a large proportion of furnace operations he thought the question of the supply of air was one to which sufficient attention was not given, and especially in the use of petroleum oil. It would undoubtedly be a very great advantage that the air should be driven in along with the fuel and with the amount of steam necessary for causing and distributing the spray. Certainly in the case of the boilers he had had to do with, the want of air had been very evident. The volumes of black smoke emitted from the chimney were a great cause of complaint against vessels using petroleum oil on the Volga; and it required the greatest care on the part of the stokers and engineers to keep down this nuisance. As to the efficiency of the fuel, he was afraid sea-going engineers still needed a large amount of education before being sent out, to enable them to make useful reports; he only wished all reports were as complete as that

which had just been laid before the meeting by Mr. Tartt. In the case of the vessel he had himself been concerned with, the engineer on his return could give very little idea of the relative value of the oil and coal: all he could say was that he could keep steam very much better by using oil than by using wood or coal. One very great advantage in the use of petroleum in steaming was that there was no opening and shutting of fire-doors, and consequently a much greater uniformity of temperature in the furnaces could be preserved.

With reference to the raising of steam very quickly, Mr. Boyd had said he thought it would be a dangerous thing to resort to this too often. That appeared to himself to be a question to which the attention of mechanical engineers should be more directed. It was very unfortunate that up to the present time no boiler had been devised in which the circulation of the water was thoroughly effected during the process of raising steam. There was no reason why this should be so. If the necessary heat could be developed from the fuel in a shorter time, as it certainly could be, why should two or three hours be required for getting up steam? In any ordinary marine boiler one hour ought to be ample. In a locomotive boiler it was found that steam could be got up in half an hour; and he saw no reason why any advantages possessed by the locomotive boiler could not be introduced into that for marine purposes.

There could be no question as to the advantage of petroleum fuel, and the importance of the present paper. For he believed the time would soon arrive when English vessels going to the Black Sea and Mediterranean would find it to their advantage, instead of carrying their coals from Cardiff or Newcastle, to take liquid fuel at some of the ports in the Black Sea or the Sea of Azof. It was quite certain that this would come about in time; and therefore contributions of the nature of the present paper to the Institution Proceedings were very valuable, and were worthy of very careful study. The question of the economy of any fuel, as Mr. Crampton had said, was very largely regulated by its price at the place, and by the efficiency with which it could be utilised on board ship. The temperature of the smoke-box also was a question which he thought had received too little attention; much valuable fuel was allowed to

(Mr. F. C. Marshall.)
go up the chimney. With only a natural draught it was of course essential that the temperature of the chimney should be high, inasmuch as upon it depended the quantity of air admitted to the furnace. For his own part he felt deeply interested in anything that could be devised for the purpose of dispensing with the chimney altogether as a draught-producing agent, and in any means for keeping the temperature of the gases in the smoke-box as low as possible; the extreme limit of theoretical perfection would of course be that they should not be much hotter than the temperature of the steam in the boiler. Personally he felt very much indebted to the author of the present paper; and he believed the members generally felt so too.

Mr. Emerson Bainbridge observed that the paper appeared to hold out no hope as to the use of petroleum refuse in this country, except for the purpose of underground work; and having himself had a good deal of experience of underground haulage in collieries, he was of opinion that neither from the point of view of economy nor from that of convenience or of safety would petroleum for such a purpose be of the least use in this country. There were only two systems of mechanical underground haulage at present in use: one was by locomotives, worked by compressed air; and the other was by ropes, employed in about a dozen different ways. The true comparison between petroleum and coal for underground work would of course be by considering both applied to locomotives. As the working of coal and other minerals went on year by year, they had to be hauled over much greater distances underground than was the case ten or twenty years ago; and at the present time it was no uncommon thing to have to carry coals underground two or three miles. For these distances there was little likelihood of locomotives ever contending with ropes, because air pipes would have to be laid for conveying the compressed air underground to the far distant point where the coal was got; and moreover the obstacles to be overcome were greater, owing to the work having to be done, as it were, in the dark. Mining engineers much preferred to concentrate at one point all their chief risk of an engine breaking down, rather than to run that risk at a thousand different points along the road.

As regarded the cost of petroleum, the price given in the paper was 21*s.* a ton; and though he did not know at what price such petroleum could be delivered in this country, he believed the present price of the cheapest form of petroleum was about four times as much. Assuming the 21*s.* to be increased only three times, say to 63*s.* delivered at works, this would have to be compared with the ordinary price of coal used for colliery boilers, which was about 3*s.* 6*d.* a ton; and assuming that the coal was utilised to the extent of about 50 per cent. in a compressed-air locomotive, this would give about 7*s.* per ton for coal when applied in producing compressed air for underground locomotive purposes, in comparison with 63*s.* per ton for petroleum: so that the price of petroleum for underground purposes in this country would come to no less than nine times as much as the price of coal. If these figures were correct, they would certainly preclude the use of petroleum.

Mr. Jeremiah Head considered that brickwork inside the furnaces fired with petroleum was absolutely essential. In the case of the locomotive fire-box shown in the drawings, a considerable extent of the heating surface was apparently obliterated by it; yet the author had been driven to have that elaborate brickwork inside the furnace to keep the combustion steady and continuous. Until Mr. Tartt spoke, he had been wondering why, seeing it was found necessary in the locomotive, yet in the marine fire-box shown in Mr. Boyd's drawing, Fig. 25, Plate 60, nothing of the kind was to be seen except the small bridge at the back end of the fire-grate. Mr. Tartt however had explained that his experience had also driven him to put brickwork in for no other reason than to make a sort of reservoir or fly-wheel for heat: and in fact it would be as reasonable to expect that oil would burn steadily and continuously without a wick, as that combustion could be steadily maintained in furnaces of that sort without something like a regulator or accumulator of the heat. All that he had heard seemed to drive him to the conclusion that it was of very great importance to heat both the petroleum and the air beforehand. In the tender where the fuel was stored, it seemed to be necessary, according to the

(Mr. Jeremiah Head.)

temperature of the atmosphere at the time, to heat the petroleum with steam, partly in order to get rid of the water mixed with it, and partly that it might be so far heated by the time it came to be burned. As far as he had been able to follow the paper, it did not seem to be very clearly explained how the air was actually got to the fuel. There was elaborate provision for introducing the steam; but it was not mentioned whether that steam brought in any air with it by acting as an injector. In passing through the furnace he supposed that for the most part, if not entirely, the steam went right through to the smoke-box as steam, that is to say, without undergoing any decomposition. Perhaps the President would tell them how far that was the case. If it were so, the sufficiency of the supply of air had not been very clearly pointed out. It had been shown that the great trouble was smoke, and that in the marine boilers there was a tendency to emit immense volumes of smoke: proving the insufficiency of air, and consequently the imperfection of combustion. Therefore it seemed to him that what was really wanted was such an improvement as should ensure that a full and sufficient quantity of air should be introduced, and also that by means of the brickwork in the furnace the temperature should be evenly maintained, so that it should not fluctuate too much; and the air as well as the fuel should be heated as highly as possible beforehand, so that, when they got to the point where combustion was desired, that combustion might take place instantly and completely.

Mr. Perry F. Nursey said that, so far as he had observed during the discussion, the question of the adoption of petroleum in England appeared to be a matter of opinion as regarded economy; but he happened to be acquainted with one little matter of fact which it might be of interest to mention in confirmation of that opinion. In 1868 he had a run on the Thames, from London Bridge to below Gravesend, in the "Retriever" of 500 tons burthen and having engines of 90 H.P. nominal, which was intended to work on the Scotch coast and was fitted up with an apparatus for burning petroleum. The petroleum furnace was that of Mr. Edward Dorsett, by whose system the petroleum was first vaporised in

a generator resembling a small vertical boiler, and the vapour was then burned in jets in the furnace. The coal-burning furnace of the vessel was altered for the liquid fuel by the removal of the fire-bars, and by the filling up of the ashpit with perforated fire-bricks, upon which the coil of jets rested. During the run the steam was kept up, and everything was perfectly satisfactory; and it was intended to continue running the boat with petroleum, which was to be supplied to her from some petroleum refining works at Deptford. At the time the boat was fitted, there was no objection on the part of those works to contract for a forward supply; but afterwards, when the plan was found to be a success and application was made to the same works to enter into a forward contract, they would not do so except at prohibitive prices: so that, as far as working in England went, that scheme fell to the ground; and he believed it was for the same reason that Richardson's petroleum furnace fell through, which had been worked for many years experimentally at Woolwich Arsenal.

On page 288 of the paper reference had been made to the fact of petroleum acting as an anti-incrustator and as a preventive of priming; and he had himself had some experience of it in both those capacities. Some years ago Mr. William Major, an English engineer in the marine service of the Danish government, had introduced the use of petroleum for preventing priming; and had applied it to several boilers with great success, particularly to the Danish royal steam-yacht, by injecting small quantities of petroleum with the feed-water. The matter had been taken up in England by himself in 1878; and amongst others two boats running on the Tyne were fitted with it, and one belonging to the Brighton Railway, running between Newhaven and Dieppe and called the "Ida." She was fitted with boilers of 50 H.P., in which there was some defect that caused them to prime so badly that they were about to be taken out, when Mr. Stroudley heard of this preventive and applied it to them. It consisted simply of a tank containing 10 or 15 gallons of petroleum, according to the size of the boat, which was fixed in a corner of the engine-room, with a pipe leading from it to the feed-pump of the boilers. The practice was, just when starting on a

(Mr. Perry F. Nursey.)
voyage, to run half a pint of petroleum into the boilers with the feed-water; and in six hours' time, when the boat got half-way across the channel, the same quantity was again injected, which lasted for the rest of the run. The result was that the priming was stopped, and there was never any more trouble with incrustation or scale; and more than that, the engine was found to be kept thereby very efficiently lubricated: thus confirming what the author said about the good effect of petroleum as a preventive not only of incrustation but also of priming. In cases where priming had occurred with the use of petroleum, he believed it would be found that rather too much petroleum had been used at first; and it would be noticed that a caution had been given in page 288 of the paper against using it in too large a quantity.

Mr. J. Phillips Bedson mentioned that some years ago, when petroleum was very cheap in the Manchester district, it was used there for firing hand-fired boilers in a manner similar to that described in the paper. His own firm being at that time manufacturers of charcoal iron, and having a large quantity of charcoal dust that they could not dispose of at any price, bought petroleum and mixed it with the charcoal dust so as to saturate it, and then burned the mixture on the boiler grate. But as previous speakers had already stated, after awhile the price advanced, and the plan had to be dropped in consequence.

Mr. W. Steele Tomkins thought it would be but fair to the author to remember that the locomotive boiler shown in his drawings was not originally adapted specially for the burning of oil. It was indeed only a make-shift for experimental purposes; and there was no doubt at all that if, as seemed likely, the burning of oil rendered it sufficiently worth his while to make a special boiler, he would alter the construction of the boiler for that purpose. It appeared to himself that the boiler might be very much simplified, so as to get rid of the expensive drop-firebox, and probably make the whole boiler cylindrical or nearly so, thereby altering it altogether. No doubt the proper proportions between the fire-box surface and the

tube surface had yet to be ascertained, when using that kind of fuel; and he believed the whole boiler would be altered, and he hoped simplified too. Mr. Boyd had remarked how much the rate of consumption varied in different months. That was so. In Russia the consumption of fuel in locomotives during the winter months was very largely in excess of that during the summer months, and the diagram, Fig. 19, Plate 58, showed this very clearly. He thought they were all indebted to the author for his valuable paper.

Mr. C. E. Cardew mentioned that he had had a good deal of experience on the State Railways of India in trying petroleum, or rather American kerosene and Rangoon mineral oil, for the purpose of preventing incrustation. Throughout the whole of northern India the railways were troubled with probably worse water for their locomotives than in any other country in the world. The deposition of scale, chiefly sulphates, was so bad that on some lines the engines could run only 100 train-miles before washing out; and it was only by a good deal of ingenuity that it could be managed to screw 150 to 200 miles out of an engine before it had to go into the shed. All sorts of plans had been tried for preventing the incrustation, or rather for loosening it so that it might come away readily when washed out; and also for causing it if possible to deposit in the form of a powder or sediment in the water, rather than as a scale adhering to the tubes and the heating surface generally. Among other things petroleum had been tried. In 1879 an engineer at home from India on leave learnt that petroleum was being used for that purpose on the North British Railway, where the water was of course absolutely perfect compared with that to be dealt with in India; and on his return he suggested to government that petroleum should be tried on some of the Indian railways. It was accordingly ordered to be tried all over the country; and after giving it an extended trial, he himself had reported that it would be an excellent thing for the purpose, if only it could be prevented from causing priming, though there was nothing novel in its use. In the paper it had been spoken of as a preventive of priming; but his own experience was that it often caused extensive priming, and that when

(Mr. C. E. Cardew.)
a train got out on the road with a careless driver it was never known when he would get home again. That was particularly so when it was first used in an engine, even when put into the boiler in very small proportions indeed. It seemed also to have the effect of searching out every weak joint in the boiler, the tubes all starting to leak badly, so much so that drivers were afraid to use petroleum. After a good deal of trial it was found that by using it in very minute quantities, very frequently supplied, they could manage to make it do its work as an anti-incrustator without causing priming. A rough-and-ready rule finally arrived at was that, each time an engine came into shed to be washed out, the tank was emptied, and a boy went in with a brush and painted the whole of its inside with petroleum. That was found to be sufficient. A very small quantity of petroleum admitted into the feed-water and well mixed was sufficient for preventing to a very large extent the serious incrustation from which the engines previously suffered; or else it made the incrustation so soft that on scraping out the inside of the boiler the stuff came away which formerly would not come away. The same plan had been tried on many of the Indian railways, some of which reported well of it, and some against it; but the general consensus of opinion seemed to be that it was rather too ticklish an expedient to be used as a regular thing.

Mr. Druitt Halpin mentioned that, with reference to the use of petroleum as an anti-incrustator for removing and getting rid of scale, he had himself used petroleum in this country for some years with water that was quite as bad as the Punjaub water, which he knew well. In a Lancashire boiler of 6½ feet diameter and 22 feet length, the incrustation extended solid about one-third of the way up the two flues at the time when he started using petroleum; and eventually it was thereby brought down to dust, so that it could easily be got rid of. The petroleum was used in exceedingly small quantities, a quart being put into the boiler once a week, when the steam was let down on Sunday; and it was Monday before the fire was lighted again. That small quantity was sufficient for the week; it kept the boiler surfaces clear of any scale, and there had never been the slightest trouble from priming.

The President quite agreed with what had been said as to the inutility of discussing the matter of petroleum fuel as a question of money. Petroleum naturally varied very much in price in different countries; and the proper and philosophical way of approaching the question undoubtedly was to ascertain the amount of duty yielded, reckoned in lbs. of water evaporated per lb. of fuel consumed. Inevitably such an event as had been referred to in the course of the discussion would take place if it were ever attempted to fire all the engines in this country with petroleum instead of with coal; for according to the table given in his opening address, he found that every year 18,936,000 tons of coal were consumed for steam engines in this country: so that, if it were attempted to substitute petroleum to that extent, there would be a speedy rise in its price.

With regard to the paper itself, he thought the length to which the discussion had gone was the best proof they could possibly have of its utility. Many questions had been entered into, which he thought the Institution of Mechanical Engineers would do well to follow up with a little more care than had hitherto been given to them. No doubt owing principally to the fact that the human race had been firing boilers for at all events nearly a century, he supposed they had been led to infer that they had arrived at perfection. Now so far as his own observation was concerned, he believed they were very far from that point; and indeed as a matter of fact he feared that serious attention enough had not been given to the subject. He was induced to make these remarks in consequence of what had fallen from Mr. Marshall, who had spoken of the temperature in the smoke-box, and had pointed out what precautions ought to be taken for avoiding any very great loss from that source. That loss might arise in one or both of two ways. It might arise from allowing the products of combustion to escape at too high a temperature, by which of course a very large amount of heat—much more than most engineers would be prepared to admit—escaped into the chimney. And this loss might be further increased by not taking care as to the proper amount of air admitted into the furnace itself. If too little were admitted, the combustion would be imperfect; and he imagined, as Mr. Marshall had pointed out, that it was probably due

(The President.)
to this cause that in the marine boilers a great amount of oil had escaped to the chimney through the tubes before it was half consumed, entailing of course a very serious loss. A loss, he would not say as serious, but of considerable magnitude, might also ensue from admitting too much air, because all excess of air had to be heated, and escaped from the boiler at the same temperature as the rest of the products of combustion; and the heat lost in that way might amount to a good deal. At the same time, while he admitted the cogency of Mr. Marshall's remarks with regard to the limit of theoretical perfection, he was far from believing it would ever be possible in practice to let the products of combustion escape into the chimney at the temperature of the steam in the boiler. That was a limit which no one could hope to arrive at, if for no other reason than that the rate at which a heated body—air for example, or any gas—was able to part with its own heat to a body cooler than itself diminished very rapidly as the two approached each other in temperature. As soon as gases got cooled down to anything like 500° or 600° Fahr., the readiness with which they parted with their heat even to cold water was very much slower than was perhaps commonly supposed; and the consequence was that, in order to get any more heat out of them, the length of the boiler would have to be extended far beyond what could be practically contemplated. But there was another objection to too low a temperature in the escaping gases. Having at one time had occasion himself to heat a large quantity of water with the least possible consumption of fuel—merely heating the water, and not raising steam from it—he had constructed a boiler 10 feet square, having two ordinary furnaces placed inside large tubes. The products of combustion on leaving the two tubes passed first along the sides of the boiler, then over the top, and lastly under the bottom, the cold water entering at the bottom and the hot water rising to and escaping at the top. Owing to the very low temperature of the products of combustion in passing along finally under the bottom, the condensation of water and of sulphurous acid upon the outside of the bottom of the boiler was so great that it corroded the bottom through in a very short time. That result of course would not take place to any such extent, and

might not take place at all, in the case of an ordinary steam boiler, because there the escaping gases had a temperature which prevented condensation.

In the paper he observed that the brickwork in the furnaces was spoken of as being a "regenerator," which was rather a misleading term, because the brickwork was there not a regenerator in any sense of the word; it was really a reservoir or receptacle of heat, or a fly-wheel of heat as Mr. Head had stated; and he had no doubt it was a very useful receptacle of heat, because it kept the gases in the furnace up to the temperature at which combustion took place readily. The well known regenerator of the late Sir William Siemens trapped the heat as it was escaping from the furnace, and then gave it back again to the entering air or gas. But no such thing took place in the furnace described in the paper; here the brickwork simply got heated up to the temperature of the fire, and was retained at about that temperature, and there was no return of the heat whatever, except to the extent of equalising the temperature under the fluctuations of the firing.

It appeared from the paper that the actual heat obtained from the petroleum was not equal to its calorific power; but he did not find that any attempt had been made to point out how the deficiency had arisen. In the first place there was no doubt that a considerable amount of heat was consumed in the spray injector; but no account had apparently been taken of the steam used in the jet. Then, in addition, there was the possibility—he did not say the probability—that a large proportion of the steam in the jet might become decomposed. Now it was well known that the amount of heat absorbed in the decomposition of water, or of any other compound, was precisely equal to the heat given out by it when its elements combined. In other words, taking the calories or units of heat according to the centigrade scale, which was more convenient than the English, there were 34,000 units of heat given out by every unit of hydrogen burnt; and consequently for every unit of hydrogen separated from its oxygen in water there was an absorption of 34,000 calories or units. Of course if decomposition took place at one part of the furnace and re-union took place at another part of the furnace,

(The President.)
there would be an equilibrium established, and thus no loss would occur: there would be absorption of heat in the part of the furnace where the steam was decomposed, and evolution of heat where water was re-formed. Supposing the steam not to be decomposed, still the whole of it had to be heated up to the higher temperature of the gases passing away from the furnace; and this no doubt would be the cause of some loss. If in addition it were the fact that part or all of the steam did undergo decomposition, and without subsequent re-union, there would be absorption of the heat required to effect the decomposition. These two factors taken together would possibly account for the actual evaporative efficiency of petroleum being, as stated in the paper, only 75 per cent. of its estimated calorific power.

However that might be, he was sure the members would all agree with him that they had been listening to a very excellent paper; and he had much pleasure in asking them to join him in thanking the author for it.

Mr. Urquhart has sent the following reply to the observations made in the discussion, regretting that he was unavoidably prevented from being present at the meeting, in consequence of being summoned at that very time to St. Petersburg, in connection with petroleum-burning in locomotives and his own recent experiments on the subject.

In explanation of Mr. Tomlinson's remark that in the south-eastern portion of Russia there is no coal, the fact is that, although coal does exist there in great quantity—the centre of the anthracite basin being Grooshefka, near the town of Novo-Tcherkask on the river Don, not far from the sea of Azof—yet the distance to Grazi, the western terminus of the Grazi and Tsaritsin Railway, is no less than 420 miles. Hence, while last year the cost at the mines was 9½ copecks per pood loaded on trucks, equivalent to 11*s.* 9*d.* per ton, the mean cost on the line is 27*s.* per ton, because transport and other dues amount to as much as 15*s.* 3*d.* per ton.

As to the practical evaporation realised with semi-anthracite coal and petroleum, the figures in the paper are based upon facts confirmed by long observation. It is only at atmospheric pressure that Welsh coal has a theoretical evaporative value of 14·30 lbs. of water per lb. of coal; while at 120 lbs. per sq. in. above atmosphere, according to the best authorities, anthracite has a theoretical value of 12·2 lbs., coal 11·4 lbs., and coke 10·2 lbs. The actual evaporation obtained with coal in locomotive practice is only from 7 to $7\frac{1}{2}$ lbs., thus giving about 60 per cent. of useful effect. In stating the evaporative duty of any fuel, the pressure under which the evaporation takes place must also be stated; and it has to be borne in mind that the 14 lbs. theoretical evaporative value mentioned by Mr. Tomlinson is reckoned at atmospheric pressure or 212° Fahr., and applies to best Welsh coal hand-picked. As to the calorific effect of petroleum, it is quite possible that fewer experiments have been made with petroleum than with coal; and indeed various estimates have been given of its theoretical value. Presumably the safest authority on the subject would be the able work of Sainte-Claire Deville (*Académie des Sciences*, Paris, vol. 68), where the analyses of liquid hydrocarbons from all parts of the world are to be found, including petroleum from the Caucasus. Very recent trials have given a practical evaporation of 12·25 lbs., and the author is very sanguine of this being surpassed when the air is heated. It must not be lost sight of that in firing with coal, even by skilled hands, cold air rushes in each time the fire-door is opened; and moreover each fresh shovelful of coal thrown in forms a damping heap, thus keeping the furnace comparatively cool. In this connection the author remembers hearing in 1876 at Birmingham the valuable paper on the Frisbie mechanical fire-feeder (see Proceedings 1876, page 318), which was intended to obviate chilling the furnace with the fresh fuel; and although that arrangement could not be applied to locomotives, yet more attention might advantageously be directed to it for vertical and under-fired stationary boilers.

Instead of building up the locomotive fire-door with brick and plating it over, the suggestion hinted at by Mr. Tomlinson occurred also to the author: namely, to do away with the fire-door hole

(Mr. Urquhart.)
altogether, and make the back plates of the fire-box solid throughout, just the same as the sides, with the water circulating between them, whereby fully $2\frac{1}{2}$ sq. ft. of additional heating surface would have been obtained in the fire-box. But as it is impossible to be certain that the price of refuse or crude petroleum will remain long the same as at present, the necessary provision must always be in readiness for rapidly reverting to coal firing; and moreover it is necessary to have an entrance to the interior of the fire-box for examination and repairs. Therefore the present petroleum-firing arrangements are merely the most simple, direct, and efficient means of adaptation to existing circumstances, keeping in view the possible rise in price of petroleum and reduction in cost of coal, inasmuch as the commercial side of the question has to take precedence of other considerations.

Having himself travelled many times on the Underground Railway in London, mostly in summer or autumn, the author was struck not so much with what he could observe or feel of smoke, as of suffocating sulphurous fumes, which he was told constituted to many persons a practical objection to travelling on that line. Hence his suggestion as to the possible use of petroleum on underground passenger railways—not for underground haulage in coal pits.

In England there appears to be a prevalent dread of the use of petroleum; but so far as the author is aware all experience hitherto with petroleum in England has been either with crude petroleum or with refined petroleum for lamps, and the use of petroleum refuse or residue is scarcely if at all known. Having made several experiments as to the safety of the residue, he finds it by no means the dangerous material against which there is so much prejudice under the name of petroleum. On the temperature of spontaneous combustion, and on the inflammability of the different petroleum products at various temperatures, he will be happy at a future date to offer some details to the Institution. Gaseous fuel is decidedly the most economical; and it must not be lost sight of that petroleum is simply fuel on its way—possibly half way—to a gaseous condition; hence its high efficiency.

In firing with petroleum it is not necessary to look at the top of the chimney for regulating the fire; it can be regulated by simply looking at it through a sight-hole in the fire-door, and as the heat is quite white a piece of stained glass may be put over the sight-hole in order that the eyes may not be dazzled.

In reference to Mr. Boyd's remarks, there are a variety of spray injectors in use in steamers on the Volga and the Caspian Sea, of which the most approved were published last year in *Engineering*; but so far as the author noticed no brick combustion chambers were used, the only brickwork being simply a protecting wall built up against the back plate of the combustion chamber in the marine boilers; and much smoke is consequently evolved by all the Volga steamers. It is simply matter of opinion whether the spray injector described by Mr. Boyd is in any way superior to that used by the author for locomotives and shown in Plate 57. It is well known how easily any round pieces of work are manufactured, and it will be seen from Plate 57 that the whole of the work on the spray injector there shown is done in the lathe, and is therefore exceedingly simple; round spray injectors are certainly in the author's opinion the best. But the spray injector of itself is of very secondary moment in comparison with the proper arrangement of brickwork in the combustion chamber for most efficiently heating the air; the latter is unmistakably the most important matter, and is that which has proved so very successful in the author's own experience.

As to the price given in the paper of 21*s*. per ton for petroleum refuse, this is the price at Tsaritsin—the eastern terminus of the railway—on the Volga, about 325 miles up the river from Astrachan. It is quite true that on the Caspian in 1882–83 the cost of a ton of residue was only from 2*s*. to 2*s*. 6*d*. at Baku, while at Tsaritsin it was 21*s*. The reason of the difference is that the petroleum is shipped at Baku in deep-sea steamers, and on arriving at the 9-feet harbour not far south of Astrachan it is re-pumped into river steamboats or barges having flat bottoms, thus entailing considerable expense for trans-shipment in addition to the cost of transport. In fact the inefficiency of transport is what has

(Mr. Urquhart.)
hitherto formed and still forms the great barrier to the more extended use of petroleum refuse. In the vicinity of Baku certainly no efforts were used to economise petroleum as a fuel; many works even paid for removing the refuse, and much of it has been run into the sea as quite an incumbrance. Owing to the present demand this waste has of course been now discontinued; but it was only when petroleum was used in European Russia proper that great efforts were made to devise means for most economically utilising it as a fuel.

The large difference between the consumption per train-mile in the trials on 8th February and 6th March 1883, as shown in Table III., is chiefly due to the difference of atmospheric temperature. A frost of 18° Réaumur or 40½° Fahr. accompanied by a strong side wind is something that railway authorities in England can have little idea of. The resistance is very great, notwithstanding a reduction of 15 to 20 per cent. in the gross load. It will be seen from Table III. that the same proportionate difference took place in the coal-burning locomotives. The great difference between summer and winter consumption owing to the inclemency of the weather in winter is a matter of universal experience in Russia.

As to the high temperature obtained with petroleum firing, the author may mention that during his first trials he noticed that many nuts on the stay-bolts of the fire-box roof dropped off from the intense heat; this never took place with coal firing. On its being discovered, he made heads on the lower ends of the roof stay-bolts; but the best arrangement is Belpaire's, where the stay-bolt is screwed into both plates—the fire-box roof and the outer shell—and riveted over, thus allowing a free circulation of water over the hottest part of the fire-box. The author quite concurs in Mr. Boyd's opinion that too rapid raising of steam in a cold boiler cannot be commended, and indeed ought to be prevented.

Referring to Mr. Rennie's remarks, petroleum firing is certainly no new discovery. The author well remembers experiments being made in Glasgow in 1862 or 1863 with shale oil from Young's paraffin works, and if he is not mistaken in the same furnace was tested American petroleum.

Exactly the same fouling is mentioned by Mr. Rennie as having taken place in the spray injectors tried on the Tigris and Euphrates that is such a source of trouble on the Volga and the Caspian. All the spray injectors that the author has seen on the Volga are connected to a vertical trunnion-pipe on the right or left side of the furnace, and the whole apparatus is so arranged that it can be swung round out of gear. But this arrangement, although no doubt convenient for clearing the spray-orifices, has its dangers. Last year on one of the Volga boats one of these spray injectors got loose while working, and by the reaction of the issuing steam swung round suddenly of itself with a strong flame on, and one of the firemen was thereby burnt to death, being unable to get out of the stoke-hole quick enough. All boats in which such flat spray-orifices are used tremble very much, in consequence of the great vibration arising from all spray injectors where no brickwork is used; and it was from this vibration that the catch got loose in the fatal accident referred to. This the author considers ought to be mentioned, in order that the necessary precautions may be taken wherever petroleum may be used.

Fouling of the spray orifices takes place from other causes besides dirt in the petroleum. In all cases where the spray injector is situated inside the fire-box amongst the flame, or even very near the flame, the author has noticed that the issuing orifices get so much heated that the liquid carbonises on their surfaces, forming indeed a small deposit of coke upon them. This fouls the orifices even more than the solid particles in the liquid; but it is very completely obviated in the author's arrangement, because the spray injector is here exposed to no more heat than that due to the steam passing through the nozzles, which is not sufficient to carbonise the liquid.

Mr. Tartt's very lucid and interesting remarks confirm the author's experience with brickwork in the furnace. Even should a special boiler be prepared for petroleum firing, the author feels confident that a refractory fire-brick surface in some form or other must form an essential element in the arrangement. Supposing the combustion chamber for retaining the products of combustion were made of copper plates alone, without any fire-brick lining, not only would there be danger in exposing the metal plates direct

(Mr. Urquhart.)

to so great a flame force, but also the temperature of combustion would be much lower, and not nearly so good a result as that now attained with brickwork would be arrived at. Moreover, should a drop of petroleum fall upon a plate having a temperature due to the water in the boiler, this temperature would not be sufficient to inflame the drop; whereas the brickwork does this most efficaciously, and thus ensures complete combustion without a vestige of smoke.

It is satisfactory to learn that petroleum exists in Arabia, however undeveloped at present. In a letter from a superintending marine engineer on the river Brahmapootra in Assam, the author has been asked whether in his arrangement it is necessary to refine the petroleum, or whether it can be used in its crude state, because at their up station petroleum is to be had, though in what quantity is not known. It will thus be seen that the subject is an interesting one in many parts of the world; and no doubt petroleum will be employed as fuel in many places where it can be had in sufficient quantity and at a reasonable price. The author has made experiments with crude petroleum in his locomotives, and finds it gives a higher efficiency than the petroleum refuse, as might be expected on account of its containing more volatile matter. No inconvenience was found in using it as a regular fuel, in conjunction of course with the brick combustion chamber. The author has little doubt that crude petroleum is to a large extent mixed up with the residue supplied to him for his locomotives; but to this he has no objection so long as the supply does not contain water, which makes weight but not fuel.

The theoretical evaporative value mentioned by Mr. Crampton as having been credited to petroleum—namely 18 lbs. of water per lb. of oil, as against 14 lbs. for coal—must have been reckoned at atmospheric pressure. Among the several ways of burning petroleum, one is by letting it drop on hot bricks, or soak through a bed of hot sand; and as no steam jet is then required for producing a spray, the theoretical evaporative efficiency of the petroleum is subject to neither increase nor diminution such as might be due to the presence of steam. Although not having the means of proving it, the author is of opinion that the high-pressure steam in the jet adds much to the evaporative efficiency attained. Some estimates

have even gone the length of assigning as much as 25 lbs. of water as the evaporative value of a lb. of petroleum; but the author considers it safer to keep within reasonable limits based upon its chemical components, and 16·2 lbs. of water is about the estimate thus arrived at for a pressure of 120 lbs. per square inch above atmosphere.

Of the air required to support combustion, part is drawn in by the injector itself; but when the engine is working at considerable power this is not sufficient, and the dampers must then be opened to admit more. With the dampers closed while standing at stations or under steam in the engine shed, the air drawn in by the injector itself is sufficient for the small fire required for keeping up the steam-pressure. By making some alterations in the brickwork so as to heat the air as hot as possible, and probably by also heating the petroleum refuse more than is done at present, the author hopes that the higher evaporative duty indicated by Mr. Crampton will be attained.

As to the suggestion about observing the temperature in the smoke-box when burning petroleum, the author has not as yet made any tests on this point, but will be very glad to do so at some future date.

With Mr. Marshall's very interesting remarks the author fully concurs, in regard to the possible future of petroleum as fuel on the Black Sea and Mediterranean. Batoum or Poti, on the Black Sea, would certainly be the most likely ports at which to get the supply.

The lengthening of the boiler tubes for petroleum firing he considers a step in the right direction; and this is undoubtedly one cause why he is getting a higher efficiency in the eight-wheeled locomotives than in the six-wheeled and passenger engines. It will be noticed that the relative advantages with petroleum over coal are not the same in each class of engine, the passenger engines having tubes about 11 feet long, the six-wheeled goods engines 14 feet, and the eight-wheeled over 16 feet long.

If the whole quantity of air required for complete combustion could be driven into the furnace by the action of the spray injector itself, that would certainly be a very good thing. But on the other hand there would then be no possibility of previously heating the air so

(Mr. Urquhart.)
supplied; whereas by creating a slight vacuum in the smoke-box, either by the blower or by the exhaust blasts, the air rushing into the fire-box through the various dampers can easily be made to pass through hot brick channels on its way to the fire. Two advantages are thereby gained:—firstly, that of heating the air; and secondly, the cooling action of the cold-air current entering through the passages in the brickwork tends to preserve the combustion chamber from rapid destruction. This latter advantage is so far proved in locomotive practice by the fact that the brickwork containing the air-heating passages has been found to last longer by at least 40 per cent. than the brickwork not containing passages for heating the air.

Having already mentioned that it was not his object in the paper to suggest any possibility of applying petroleum firing to underground engines in coal pits, the author will only add, with reference to the remarks of Mr. Bainbridge, that in his own opinion compressed air is the only safe and ready means of working underground engines at various points in the workings of a mine.

He is glad to observe that the brickwork in the combustion chamber is considered by Mr. Head an essential element for successfully overcoming the difficulties of practically applying petroleum as a fuel; and the expression "fly-wheel for heat" very clearly illustrates the part played by the brickwork, more especially in locomotives, where every mile run requires incessant manipulation for thoroughly working to advantage, each grade calling for its corresponding alteration. It must be admitted that within the limits of a locomotive fire-box much cannot be done in the direction of heating the air; but what is possible ought to be done. He fully concurs with Mr. Head that the heating of the liquid as well as of the air, prior to their coming into contact in the combustion chamber, is just what is wanted for attaining the maximum of efficiency. As to how the air is got to the fuel, the author of course resorts to the exhaust when running, and to the blower when making steam to begin with and when not running, whereby a vacuum of about 2 inches of water in the smoke-box is found by direct experiment to be obtained.

It may here be mentioned, with regard to the warming coil in the petroleum tank on the tender, that the arrangement described in the paper (page 278) and shown in Fig. 5, Plate 53, with an upward course for the steam through the coil, was that first employed by the author. But practice showed this to be a little defective, on account of the condensation in the coil forming a head of water, against which the steam had to force its way up; some inconvenience arose from the consequent squirting of the water out at the top of the outlet pipe, and in fact in some cases the coil got frozen up. Ultimately therefore it has been found more convenient to reverse the arrangement, giving the steam a downward course through the coil by admitting it at the top and discharging it from the bottom, so that the water drains out freely of itself, no cock being used on the outlet side.

Petroleum refuse is undoubtedly a very effective and cheap means of preventing boiler incrustation; and the author has heard from several other engineers in Russia that they have found it equally successful. He is glad to notice also that in India and elsewhere petroleum has proved so effective as an anti-incrustator. Much will depend upon the chemical qualities of the feed-water, as to how often and in what doses the petroleum ought to be injected into the boiler.

While the arrangements described in the paper are in the author's opinion and experience the simplest and most direct way of utilising liquid fuel in existing locomotives, he agrees with Mr. Tomkins that it is quite possible there may be some special way of utilising it with a higher efficiency, by making a special boiler and furnace.

As to the necessity, pointed out by the President, of admitting the exact quantity of air requisite for complete combustion, and avoiding the admission of any excess of air, this was one of the most difficult points to overcome; and notwithstanding all the care taken in supplying means of minute regulation, it was only after the drivers got convinced themselves of the necessity of very exact regulation that good results ensued. The author has found that the men get quite to understand this, as both the driver and fireman now manipulate the whole with very creditable results. For instance, when starting from a station, smoke was invariably noticed at first,

(Mr. Urquhart.)

but now, after some experience, the same men so carefully manipulate the supply of fuel and steam and air that no smoke is seen in starting from a station, and they gradually increase each of these three elements until full speed is attained.

It is quite true that the brickwork of the combustion chamber is not a regenerator in exactly the same sense as it is in a Siemens gas furnace where alternate reversals take place of the gas and air currents. But just as the preparation of the two elements, which constitute the fuel, for being ultimately burnt in the furnace is effected by the brickwork in the Siemens furnace prior to their coming in contact, so the heat absorbed by the brickwork in the locomotive fire-box tends to elevate the temperature of the gases generated from the fuel, thereby very much increasing the temperature of the fire, or regenerating the heat. Possibly the brickwork in the present case, in so far as the heating of the air is concerned, might be taken to correspond with Ponsard's gas furnace, which has a recuperator for heating the air; or with the well known heating furnace of Boetius, in which the combustion chamber is encircled by channels for heating the air not from waste gases but by the heat of the combustion chamber itself. Certainly the brickwork acts as an equaliser of fluctuating temperatures under varied circumstances, whether the locomotives be running or standing.

As to the proportion obtained out of the full calorific value of the petroleum, it can scarcely be expected, especially in a locomotive, that the same splendid results can be attained as by gaseous fuel in a Siemens regenerative furnace with reversible currents. In locomotives there must always be a considerable percentage of heat escaping up the chimney.

At some future time the author will be very glad to supplement the present paper with whatever further may seem of value and interest to the Institution on this subject.

ON THE CAUSES AND REMEDIES OF CORROSION IN MARINE BOILERS.

By Mr. J. HARRY HALLETT, of Cardiff.

Marine engineers are all striving in various ways to attain increased economy of fuel in steamers. Among other means of doing so, triple-expansion engines of high initial pressure are being introduced, which appear to be gaining much favour, and will no doubt in time supersede the ordinary two-cylinder type. The increased pressure of steam evidently renders it necessary to be still more guarded than hitherto as to the Deterioration of Boilers. Steel boilers are now in very general use, and there can be no doubt as to their efficiency ; but the writer's experience is that they are equally liable with iron boilers to corrosive influences. On careful scrutiny he has found in steel plates severe corrosion concealed by a very slight scale, upon the removal of which the plate has proved to be covered with a black substance, probably a black oxide of iron. In many cases a casual inspection may fail to detect this. Internal corrosion is well known to be most erratic in its action ; it attacks the metal in different parts of a boiler, in different ways, and from various causes. The principal sources of corrosion however may be discussed under the two heads of defective design and defective management: which is equivalent to saying that an ordinary marine boiler will hardly be subject to corrosion at all, if well designed and well managed.

Design.—The most frequent fault of design which bears upon corrosion is the want of sufficient space for allowing a thorough examination to be made of every part of a boiler. The tubes are often placed so far out in the wings that it is impossible to get down to look at the sides of the furnaces, or so close to the furnace crowns

that there is no room to get over these. In the boiler shown in Figs. 1 and 2, Plate 61, it would be preferable to allow at least nine inches between each furnace crown and the bottom row of tubes, especially as this row is not useful as heating surface when placed so close down to the crown.

The manholes are often inconveniently placed and made too small, which always affords an excuse for a want of proper attention on the part of the men in charge. Manholes should always be fitted in the wings if the size of boiler will allow. A manhole at the bottom of the back end, as shown at M in Fig. 4, Plate 62, is also to be recommended. There can be no doubt that the best way to prolong the life of a boiler is to watch it carefully and constantly, so as to note the commencement of deterioration and take steps to check it. In any part which cannot be seen, it is impossible to know what is going on.

Another fault of design, which easily escapes notice until too late, is the pitching of the steam-space stays, so that one or perhaps several of them come over a space, instead of over a tube, thus rendering the effective use of the scaling tool very difficult or even impossible in that particular vertical space. With the object of securing the conventional 20 sq. ft. of heating surface per horse-power, the tubes are sometimes too closely pitched, which causes bad circulation, besides rendering the spaces liable to become soon choked with scale. The tubes should never be less than $1\frac{1}{4}$ inch apart, both vertically and horizontally.

Management.—The first point to be looked to in the management of a boiler is the circulation. In an ordinary multitubular marine boiler, such as is shown in Figs. 4 and 5, Plate 62, the circulation takes place by the water ascending from the furnace crowns, and from the sides, backs, and fronts of the combustion chambers, and descending at the wings; the tubes do of course somewhat obstruct the upward current. There can be no doubt that the coolest places in the boiler are those where the circulation is most defective, as is naturally the case below the level of the fire-bars. The water in this part of the boiler always contains the greatest percentage of

solid matter, and here the greatest deterioration may therefore be expected to be found.

Double-ended boilers are not only subject to the same corrosive action as single-ended ones, but being longer they are also more prone to suffer from racking strains, due to the difference of temperature between their upper and lower parts. One method of reducing this difference as far as possible is to fit the internal feed-pipe so that it is led along on a level with the upper tubes, so as first to warm the water inside it, and is thence carried down so as to discharge the warmed water in a horizontal direction at the bottom of the boiler.

The scum pipe should be fitted with a pan, as shown at S in Figs. 4 and 5, Plate 62, shaped like an inverted saucer, and placed just above the level of the water for the scum to collect under it; and it should always be blown off upon raising steam, and also about once a day when under weigh. The blow-off cock should either be attached at the bottom of the boiler, or else an internal pipe should be fitted to it, reaching down to the very bottom.

Salt is not deposited until the density of the water exceeds 4-32nds by the salinometer, that is, until there is more than 4 lbs. of salt in 32 lbs. of water; beyond this proportion the deposition of salt then begins upon the furnace crowns, &c. It is recommended that the opportunities occurring from time to time by the engines being stopped should be taken advantage of for pumping up the boiler to the top of the gauge-glass, and then blowing it down to the bottom of the glass. This repeated about twice or thrice on each occasion will work wonders. The great usefulness of this plan arises from the fact that while the engines are stopped there is little or no steam being made, and therefore no solid matter is being deposited from the water; so that the extra feed-water pumped in at that time does much more to freshen the boiler than it would if the engines were at work. When in charge of the engines of a steamer on a voyage from England to Rangoon, calling at several ports on the way, and thence to Venice, the writer kept water in the boilers continuously during the whole round, that is to say the boilers were never entirely run out and refilled, but were blown down from time to time as above

described. They were under steam about seventy-two days, and upon being opened out at the end of that time had only a slight scale upon them of uniform thickness, and no indication of pitting or corrosion.

The mode of treatment adopted by the writer for new boilers is to have them well washed out before filling, then to run them up, and when they are filled with water up to the normal height, to throw into each through the top manhole about a bucketful of common soda. When steam is raised to about 30 lbs. per square inch, blow out a little through the scum cock. Before adding any more water, start the feed donkey, and let it deliver for some time over the side of the ship, so as to get rid of any dirt &c. in the pump; this is a very useful precaution to observe whenever the feed donkey is employed. After starting the main engines, let them run at first with the feed-water overflowing from the hot-well into the bilges; this will clear the condenser. When under weigh, it is advisable to use the blow-down cocks sparingly.

The appearance of the water in the gauge-glass shows at a glance the state of the water in the boiler; if the glass is at all dirty inside, that is proof positive of the water not being clean enough; and this can be cured by the use of the scum cock. In a double-ended boiler a scum pipe should be fitted at each end. The scum pipes are sometimes so fitted that their position can be altered to suit the trim of the ship, which is a point of far more importance than is generally imagined. After a run, when steam is finished with, the water should be blown out from the bottom, and the boilers then kept thoroughly dry. Before refilling they should be carefully swept down inside, and washed out.

There is no doubt that one of the most active causes of deterioration in boilers is the want of proper care in their treatment. Cases have come under the author's notice of boilers being blown down as far only as the level of the bottom manholes, and refilled, without care being taken to draw the water out of the bottoms. This process having been frequently repeated, the water at the bottoms became so impregnated that the heads of the rivets and the lower half of the compensating rings round the manholes

were corroded away, while the other parts of the boilers were in good condition. Many good boilers are ruined through careless management, and the makers are wrongly charged with allowing their work to come from the shop not properly finished.

Another example, out of numerous cases met with, is that of a pair of boilers which were fitted some little time ago with hydro-kineters, or internal steam-jet nozzles for stimulating the circulation of the water in the cooler spaces below the furnace-flues. Upon a recent examination the valves of these appliances were found to be hard and fast, in consequence of carelessness in supervision. Another great evil is raising steam too quickly, and blowing out under too great a pressure, which cannot be too strongly condemned.

Corrosion in the upper parts of the boilers is principally caused by the introduction of oil, tallow, and other greasy substances from the engines. In all the steamers with which the writer is connected, he has discarded the use of all oil or other lubricant in the cylinders, with the most satisfactory results.

Various remedies have been suggested for preventing corrosion: among others, air-extractors, and circulating tubes. Zinc has been tried, both cast and rolled, and some engineers report favourably on its use; but to make it effective, very large quantities must be used, as it so quickly oxidises, and thus loses its protective qualities. The electrogen of Mr. Hannay's invention, which is rapidly gaining favour, is a very simple little appliance, and, as far as the writer has experimented with it, is very effective. It consists of a ball of zinc cast upon a copper bar, and then hammered to make it more impervious to the action of the water; on each end of the copper bar a wire is soldered, and the two wires are again soldered to different parts of the boiler so as to obtain metallic contact. Its principle is the setting up of galvanic action in the boiler, and making the boiler together with the ball of zinc a galvanic battery, metallic contact being absolutely secured, and thus the ironwork protected from corrosion. Boilers which had shown a tendency to corrosion looked quite healthy in a very short time after these appliances had been fitted to them.

Marine boilers are not troubled with much external corrosion, especially modern boilers, because much more care is now taken in fitting them into the ships than was formerly the case. They are now properly coated, and are not fitted too close down to the bottom of the ship, plenty of room being allowed for access to the seams. But that all the mischief to be contended with is not confined to the waterside of the boiler is shown by the following incident. Some four and a half years ago the writer was called in to survey a boiler that had exploded and killed the chief engineer and fireman. Upon examination it was found that the bridges had been built up close to the backs of the combustion chambers, as illustrated in Fig. 3, Plate 61; the dirt &c. had been allowed to accumulate for some time, and corrosion had been going on upon both sides of the plate without being noticed. After the accident, when all had been cleared away, the iron was found to have oxidised so much that in some parts it was barely $\frac{1}{16}$ inch thick; hence the explosion. The backs had been so built up for the express purpose of economising fuel; but experience goes to prove that this is a fallacy, and many cases could be mentioned where similar bridges have been taken out without making any difference in consumption of fuel, except that, if anything, the economy has been in favour of their absence. There is nothing like cleanliness to prolong the life of a boiler.

When a vessel is to be laid up, a good plan is to pump the boiler full up to the very top of the dome, and keep it so until it is again required. Another method of preserving a boiler not in use is to empty it and clean it thoroughly, then close all the manhole doors except one at the bottom, put in a small stove full of burning coke, and close up the bottom door quickly. The object of both these methods is of course to exclude air as thoroughly as possible.

Discussion.

Mr. J. R. FOTHERGILL said the question of corrosion and pitting in boilers was one of the most perplexing difficulties marine engineers had to deal with. Its peculiar and erratic action had hitherto completely defied sound explanation, and had thus led to the promulgation of many theories. Anyone who would study the parliamentary blue book of the committee appointed to enquire into this matter must feel extremely perplexed at the many different opinions and theories therein advanced by engineers and chemists who had given the matter their close consideration. He agreed with the author that defective design might account for much, particularly in cases of bad circulation; but this applied more to old boilers than to those of the present day. No doubt the changes advised in the paper would be beneficial, by allowing free access throughout the boiler; but practical difficulties frequently intervened, and those changes, he submitted, would not do away with corrosion, as it occurred not only in those parts of the boiler which were rather inaccessible, but also in those parts which were quite accessible to easy and thorough examination. He must differ from the author in attributing so much to bad management, seeing that the true cause of corrosion could not be pointed out with anything like certainty. Of course good and careful management might do much to protect the various parts, by keeping them covered with a uniform thin scale; but it was most difficult, particularly on a long voyage, to ensure such a scale. His firm had several steamers running to the East, and he had found it necessary to clean frequently such parts as the tube-plates &c., whereas the other parts in many instances were barely protected by any scale at all. From many experiments he felt satisfied that one of the greatest causes of corrosion was the atmospheric air which was introduced into the water as it was thrown into the hot-well by the air-pump, and was thence carried into the boiler by the feed-pumps. As a confirmation of this view it would be found that, if a strip of iron plate were suspended in the passage leading from the foot of the condenser (of course a *surface* condenser) to the air-pump, it would remain through an

(Mr. J. R. Fothergill.)
Indian voyage with scarcely any sign of corrosion; but if a similar piece of plate were suspended in the feed-pipe, it would be destroyed in a very short time. In such a case the plates were exposed to exactly the same water, except that in the one case the water contained no air, being in a vacuum, and in the other it was charged with air. The grease and oily matters also which came from the cylinders possessed the property of combining with the solid matters of the water, forming with these solid matters a frothy scum and mud, which did not seem to have any scale-forming capabilities, thus causing the iron surfaces to be left unprotected and exposed to the action of the oxygen of the air carried in by the feed-water. Having had many samples analysed of this mud and scum, he found in every case that they contained from 10 to 20 per cent. of oily matter, according to the quantity of oil used. Pitting appeared to be promoted by small portions of oil and grease, which were circulated with the water, and in their course came in contact with and adhered to unprotected surfaces, thereby facilitating oxidation. If in any cheap and practical manner the feed-water could be delivered into the boiler free from all oil, grease, or atmospheric air, he was strongly of opinion that there would be very little trouble about corrosion. Although this view might not account for every case of deterioration, inasmuch as there were evidences of other causes being at work, yet he believed it would account for 90 per cent. of the destruction which took place.

In pages 334 and 335 of the paper it was stated that "cases have come under the author's notice of boilers being blown down as far only as the level of the bottom manholes, and refilled, without care being taken to draw the water out of the bottoms. This process having been frequently repeated, the water at the bottoms became so impregnated that the heads of the rivets and the lower half of the compensating rings round the manholes were corroded away, while the other parts of the boilers were in good condition." Would the author kindly say what the water became impregnated with? He presumed it would be with solid matters of some sort, which might be in suspension, but certainly not in solution. The boiler might have a defective circulation, and the cold water might sink to the bottom

where the circulation was sluggish, and remain there some time; but he was certainly of the opinion that the difference in the amount of solid matters in solution in different parts of the boiler would be very slight, if anything: in fact the law of diffusion of liquids would prevent such a difference. On page 333 he noted that the author described the feed-pipe being carried down to the bottom of the boiler, and there delivering the feed-water. By this method however all the air, grease, oil, and other matters carried into the boiler with the water were brought in direct contact with the iron on their way up to the surface. He had himself found considerable advantage in delivering the feed-water across the surface of the water in the boiler, for the air was then liberated at once and carried off with the steam. The following plan would effectually avert pitting:—the pitted places should be scraped, well washed with a strong solution of soda to remove any grease or acidity, and then washed with Portland cement.

In page 335 of the paper he observed it was stated that the author had discarded the use of all oil or other lubricant in the cylinders; and he should like to ask whether that statement included the lubrication of piston-rod and slide-valve rods, or what was technically called "swabbing" the rods. He knew several instances in which the lubricator had been cut off, but in nearly every case it necessitated an increase of swabbing; and thus he was afraid even more oil would find its way into the cylinders from that source than if a little oil were used in the lubricator. For his own part he should not like to try the effect of cutting off all lubrication from the slide-valves or pistons.

With regard to blowing the water out of the boiler when a steamer entered port and the steam was done with, he thought that would be a mistake; for after the water had been blown out of the boiler, although the fires had been drawn previously, the various internal surfaces were still left sufficiently hot to cause a quick evaporation of the moisture from any substance that was deposited upon them, changing carbonate of lime to arragonite, and sulphate of lime to an anhydride having the hardness of a natural mineral; and this had been frequently proved to himself by the difficulty he had experienced

(Mr. J. R. Fothergill.)

in removing the scale. He would therefore strongly recommend that the water should not be blown out by the steam, but should remain in the boiler till it had cooled, and should then be run or pumped out.

This question of boiler corrosion involved many points of interest, such as the use of zinc, soda, and lime; electric or galvanic action; the decomposition of the salts of sea water and the formation of acids; the effect of increase of temperature; the composition or different qualities of iron and steel; and particularly the use of mineral oils for internal lubrication. Mineral oils he was satisfied had acquired a reputation much in excess of their true character; and as the boiler pressure and consequently the temperature increased, he thought this would very forcibly be shown to be the case. He had purposely avoided discussing the question of corrosion from what might be termed a chemical point of view; but he had had numbers of analyses made of deposit, scale, water, &c., and was now endeavouring to trace the action of mineral oils on the salts of sea water under various temperatures. Should the results prove of the value he anticipated, he should have great pleasure in laying them before the Institution on a future occasion.

Mr. Sydney F. Walker would consider the subject of boiler corrosion from the electrical point of view. From a study of the present paper he was inclined to attribute to electricity or galvanic action a large portion of the mischief of which marine engineers complained; but he thought electricity would as usual find its own remedy, at any rate for that for which it was responsible. A good deal of the pitting to which reference had been made he should ascribe to impurities in the iron, and to different qualities of iron. It was well known that a galvanic battery existed wherever two dissimilar metals were together in the presence of a liquid, more especially an active liquid such as sea water; and by dissimilar metals were to be understood not only metals as dissimilar as zinc and copper, but different qualities of the same metal, such as cast iron and wrought iron, or iron and steel. Therefore it would appear that one of the first necessities for lessening corrosion would be that so far as

possible the boiler should be made of one substance all through. Putting aside the local action due to inequalities in the iron, he was of opinion that, when the heated water in a boiler contained certain salts, such that the gases composing them had a greater affinity at that temperature for the iron of the boiler than for the metals with which they were already combined in the salts, then of course the iron was attacked, taking the place of the other metal in the salt. But when a piece of zinc was put in the boiler, or a piece of any other metal for which the gases in the salts had a greater affinity than for iron, the iron was thereby protected so long as the zinc retained a surface which could be attacked. In page 335 of the paper it was mentioned that both cast zinc and rolled zinc had been tried; but that it so quickly oxidised, and thereby lost its protective qualities, that very large quantities had to be used in order to render it effective. This he understood to mean that very large quantities had to be used, because if a small quantity was put in it would not last any length of time. Any electrical engineer who had had much to do with batteries must have been troubled with that very difficulty. It was not a question of whether the zinc were cast or rolled, except in so far as the particular process of preparation might have affected its purity. What was really wanted was pure zinc; but pure zinc unfortunately was not to be obtained in commerce, at least within his own experience. In a galvanic battery the more impure the zinc was, the more trouble would be encountered. In practice the purest zinc was obtained that could be got, namely the best rolled or drawn; which was afterwards amalgamated, that is was caused by a simple process to form a sort of alloy with mercury. The mercury seemed to get right into the substance of the zinc and alter its character altogether; it became so brittle that, instead of being capable of being bent easily, it would break if it were not carefully handled; but the mercury gave to it apparently, so far as the battery was concerned, the properties of pure zinc, especially for liquids of moderate power. Where sulphuric acid was present, the zinc required to be frequently amalgamated afresh. He would suggest that for marine boilers amalgamated zinc should be tried; and he should anticipate that, if

(Mr. Sydney F. Walker.)
the cause of ordinary cast or rolled zinc losing its protective properties was that it quickly got corroded and used up, then the use of amalgamated zinc would be beneficial. The suspension of a piece of zinc in the water of a boiler not only offered to the gases present a metal for which they had a greater affinity than for iron, but it also immediately created a galvanic battery. In the paper he observed that the electrogen was the only application mentioned of the principle of a galvanic battery; but it was not possible, he thought, to suspend a piece of zinc in an iron boiler without immediately creating a galvanic battery; and the apparent success of any such appliance as the electrogen in protecting a boiler would depend upon the intelligence with which the galvanic principle was applied. There were two points with regard to the electrogen which he wished to notice. The first was that good results might be got from any plan which would lessen the electrical resistance of the boiler. For instance, with the ordinary plan of suspending a piece of zinc a current might be passing from the zinc through the water to the iron boiler, and back by means of the iron boiler to the zinc; but there might be parts of the iron boiler-plates which were more or less remote from the zinc, and which were not in very good communication with one another electrically, and consequently might possibly not be so well protected. He was therefore strongly inclined to think that an ordinary piece of amalgamated zinc, connected by wires with many parts of the boiler, would have the same effect as was ascribed in the paper to the electrogen. The other point with regard to the electrogen was that he should like to know the appearance of the copper. A zinc copper couple produced a more powerful galvanic action than a zinc iron couple; and he therefore believed the electrogen possessed much greater advantage in conveying the galvanic current, and in decomposing the liquid salts and causing their gases to act on the zinc, than where there was only a zinc iron couple. If that was so, perhaps even a better result still would be obtained by suspending separately within the water both a zinc plate and a copper plate, each of them having a wire or a strip of metal of its own substance connecting it with the iron boiler. The same train of reasoning would further lead to suspending merely a plate

of iron in the boiler, insulated from the rest of the boiler, and fed by a current of electricity from an external source; then, in accordance with the well-known process of electro-plating, the iron suspended would draw to itself all the active qualities of the gases liberated in the decomposition; and the boiler itself would be left perfectly free from any corrosive action.

Mr. Charles M. Jacobs agreed that the question of the cause of corrosion in boilers was one that had troubled marine engineers for a great number of years. The origin of the difficulties from corrosion he thought might be traced more especially to the commencement of the use of high pressures and of surface condensers in compound engines. Corrosion was indeed, as mentioned in the paper, so erratic in its action that he would not attempt to propound any theory respecting it; but would only mention a severe case in point, and the remedy that had been adopted to stop the corrosion. The case was that of a vessel built about four years ago, which proceeded on a voyage to the Mediterranean, where she traded for five months. The boiler was not opened out during that time; and on her return an examination was made, when it was found that the screw stays were reduced from $1\frac{3}{8}$ inch diameter down to $\frac{3}{4}$ inch in the five months. Round the seams of the combustion-chamber holes were pitted $\frac{5}{16}$ inch deep. The boiler was considered at the first glance to be ruined. It was an iron boiler with three furnaces, like that shown in Fig. 1, Plate 61. The furnaces were pitted along the sides in a line with the fire-bars; the combustion chambers were pitted on the crown and down the vertical seams. The screw stays were practically ruined, and nearly all of them had to be taken out. The parts of the plates that were pitted were carefully cleaned and washed with petroleum and cemented with Portland cement, the boiler was washed out, and from that day to the present the pitting had ceased, and the boiler was running just as it was altered five months after it was delivered. There was only one structural alteration connected with the corrosion, and that was in the position of the feed-pipe, which had previously been carried along just below the water-level, between the crown of the combustion chamber and

(Mr. Charles M. Jacobs.)
the first tier of stays; that pipe was removed, and the feed was led into the steam space and delivered the feed-water into the steam space. By thus getting rid in some measure of the air in the feed-water, which he believed was a considerable cause of corrosion, and by keeping the Portland cement well preserved, the boiler was now running in just as good condition as when it was started.

The question of corrosion was so difficult that it really required the most careful consideration: the more so because the cost of marine boilers was increasing as their pressures increased. He thought they were all much obliged to the author for drawing attention to this subject, which was certainly one of great and growing importance.

Mr. F. C. MARSHALL said he had hoped that, after the very exhaustive enquiry and report issued by the Admiralty on this subject, they might have had from Mr. Bakewell, one of their members, who was in the room a short time ago, a summary of the practical results arrived at by the Commission. He quite agreed with Mr. Fothergill that in studying the report they would be very much puzzled to arrive at any conclusion as to the best means of treating marine boilers. The evidence was very conflicting; and it was of importance therefore that they should know what the Admiralty themselves, who had perhaps more experience than anyone else and a more skilled staff of agents, regarded as the practical result of that Commission. He trusted therefore Mr. Bakewell or some other members of the Admiralty staff might be induced to add as an appendix to this discussion a statement of their practice and of its results so far as it had already gone.

A great many points had been hinted at in the course of the discussion, all of which had received consideration from time to time, and he believed every one of the cases mentioned might be attributed to one or other of the forms of corrosion. He had himself had experience of one special case, with reference to the point mentioned by the author of leaving water in the bottom of the boilers. A vessel fitted out on the Tyne by his own firm lay for some time in the river, and had steam up frequently. On each

occasion the boilers were run out and refilled with water. She went round to Glasgow, and lay there for five weeks. In starting on her voyage she had a collision, and had to return and lie up for another three or four weeks. On every occasion the same plan was pursued of emptying and refilling the boilers. The effect on the boilers was such that on her first voyage, in returning from Alexandria to Liverpool, the tubes, which were of iron, gave out one after another; and before she got to Liverpool about a hundred tubes had failed; and he need scarcely say that his firm were very seriously blamed for having put such bad tubes in. With a view of arriving at the cause of so serious a failure, the boilers were very thoroughly examined. They were double-ended; and naturally, the vessel being as a rule by the stern, the after end of the boilers was lower than the forward end. On drawing all the tubes that had failed, and examining all the other tubes that came into view as these were drawn, it was found that they were all pitted in one locality, namely at their after or lower ends: that is, in the after nest of tubes the pitting was at the ends over the furnace doors, next to the uptake flue to the chimney; and in the forward nest the tubes had their ends pitted next to the flame-box: showing that the inclination of the boilers had something to do with the cause of the pitting. On carefully examining every tube, it was found that here and there over the lower third of its circumference were brown spots of rust, where drops of water, probably not more than a quarter of an inch in diameter, had trickled down and collected after the boilers had been emptied. On scraping off the rust at each spot, a small black speck was found, which could be dug out with a knife; these specks became gradually small holes of from $\frac{1}{16}$ to $\frac{1}{8}$ inch diameter. The cause appeared then to be clear: that, instead of being entirely emptied and dried, the boilers had been left from time to time with just a little water in the bottom; this water had kept the surfaces of the tubes damp, the moisture had trickled down to the under side of the tubes and formed small drops, the drops in drying had oxidised the iron, and thereby a small hole had been gradually eaten through in the centre of the moist spot. The inference therefore was that the pitting arose from the moisture that

(Mr. F. C. Marshall.)

was left in the boilers, which he believed had been the cause of the failure in that case. What there was in the centre of the drops, or what the action was upon the tube itself, whether galvanic, chemical, or otherwise, he was not prepared to say.

In another very serious case of corrosion he had found that the side plates of the furnaces in an iron marine boiler were all eaten away in flat patches in two of the furnaces, thinning the plates to about two-thirds of their original thickness; and these patches were all of them in a direction distinctly in the line of the fire-bars, neither above nor below. This indicated that the corrosion had something to do with the fire-bars, and with the condition in which they were from time to time in the working of the boiler. It also indicated to his mind that the cause was a galvanic or magnetic action on the surface of the plate, due to the material being in a different electrical condition in the line of the fire-bars, and above and below that line. Had the corrosion gone on a little longer, the furnaces would have collapsed at that line.

With reference to the admission of air into boilers, there could be no question that the less air was admitted the better, and that its admission might to a large extent be prevented by careful arrangement of the feed-pumps. Too often the whole of the air drawn out from the condenser was forced into the boiler without any opportunity of escape. Great attention had been paid to that point by Mr. Douglas Hebson, with the result that his boilers knew nothing of corrosion, at least from that cause.

With regard to the introduction of petroleum for the protection of the surfaces of boilers, it was a common practice of some marine engineers abroad, as for instance at the port of Genoa, to use petroleum in their boilers for the purpose of protecting the surfaces from corrosion, and also for preventing incrustation ; and its use was attended with very great advantage indeed in both those respects. In the case also of the salt water of the sea, with which the boilers were fed, it prevented any chance of priming.

With reference to steel boilers, of which his firm had had some experience, they found corrosion in steel boilers to be less if anything than in iron boilers. It was rather too soon to speak

more fully on this subject, because steel boilers for marine purposes had as yet been in use only three or four years at the outside; but he might say that, although the steel boilers were fitted with iron tubes, no difference was found, and no greater tendency to pitting of the iron tubes than where they were fitted into iron boilers.

Mr. Hallett said that, having been himself a marine engineer for fourteen years, he had had a good deal of practical experience with marine boilers; and in the case of every boiler which he had examined he had found that by means of careful attention pitting had been stopped. Yesterday the steamer "Blue Jacket," which was now in port, had been visited by a number of the members, who had seen that the process recommended in the paper was being adopted with regard both to the boilers and to the cylinders (page 335). They had seen that there were no lubricators on the cylinders at all; he had had them taken off. The cylinder surface was like glass. As to the discarding of internal lubrication in the cylinders of marine engines, he failed to see how any lubrication could find its way into the cylinders through the high-pressure glands; and when these were properly packed they required very little lubrication. For that purpose he generally recommended Bremner's valve-oil, as it left no deposit and did not evaporate at 600° Fahr. and was a capital lubricant. When the "Blue Jacket" cylinder was examined yesterday, it had been remarked by one of the members that the wall of the cylinder was greasy; but this was solely due to its having been wiped over with paraffin oil to protect it from corrosion prior to inspection. When the steam-winches and donkey engines on board steamers were examined, their valve-faces and cylinders were invariably found to be in capital condition, though they never got any lubrication.

In the boilers it was not only corrosion that had to be contended with, but also the accumulation of scale. In the case of the "Blue Jacket," she had returned home from her first voyage in very good condition; but on her second voyage the boilers started pitting along the line of the fire-bars, in the manner referred to by Mr. Marshall, and on examination he found that the pitting had extended also to the

(Mr. Hallett.)
tube-plates. He had the rust cleaned off, and the pitted holes filled up with red lead, which had now been in for about six months, and had answered so well that one of the members who went through the boilers on the previous day did not discover the pitting, and said he had never seen boilers in better condition. In this case the pitting was of no moment, having gone to no depth before being covered up with red lead, whereby it was entirely stopped.

As to the electrogen, not being himself an electrical engineer he was much obliged to Mr. Walker for the remarks he had made; and he would only mention that, having fitted the "Blue Jacket" steamer with these appliances, he had found that after they had been in about nine months there was a uniform scale right through the boilers, and that the boilers were protected from any action or corrosive influences which might arise either from the presence of free oxygen or from the use of oil or from any other cause.

Variations in the quality of boiler plates did certainly cause very sensible local currents of electricity to be set up, resulting in the decay of positive parts, which were generally the purer parts. In the same way, in a zinc plate used in a galvanic battery, local currents in the plate would soon destroy it without giving out any effectual current. For this reason the plate of zinc for batteries was amalgamated; the mercury dissolved only the pure zinc, and formed, as it were, a plate of pure zinc, which was brought into contact with the acid used in the battery; thus local and ineffectual currents were prevented. The local currents in the plates of boilers were prevented by the over-ruling current set up by the electrogen. In sea-water there was no salt that contained any gas having greater affinity for iron than for the metal with which it was combined in the salt; the corrosion of iron he considered did not depend upon the decomposition of any salt, but upon the action of water containing free gases upon the iron in presence of salt. A piece of bright steel would remain quite bright in salt water which had been boiled in vacuo till all free gases had been expelled; but upon the admission of ever so little air the steel would rust. If however the steel had a piece of zinc attached, it would not rust on admission of air, but the zinc would rust or decay.

As to the opinion that it did not matter whether the zinc were cast or rolled, it should be remembered that at a given temperature the properties of zinc could by hammering be quite altered, from a crystalline friable condition to a malleable one. The waste attending the use of cast zinc for preventing corrosion in boilers arose from the circumstance that the zinc, when cast, crystallised into large crystals, and when afterwards placed in boiling water the oxidation took place down the planes between the crystals, splitting the slab of zinc into many insulated little pieces, and so destroying its value as a protective: that value depending entirely upon good conductivity, which in its turn required continuity of substance. In hammered or rolled zinc, if treated at the proper temperature, no such splitting took place. Amalgamated zinc had been tried for boilers, and had failed, for the reason that weak excitants like sea-water failed to act to any great extent on zinc when amalgamated, the mercury effectually protecting the zinc from corrosion. It was only by the decay of the zinc instead of the iron that the boiler could be saved.

As to attributing so much to management, he could quote numerous cases that had come under his personal supervision, both in long and short voyages under varying circumstances, where severe pitting and corrosion had been overcome by careful management. Having himself had charge of machinery at sea, trading to all parts of the world, he had had some experience in this matter, and had always been able to contend successfully against the difficulty, never having had any pitting or corrosion whatever; by treating boilers in the manner suggested in the paper he had always been successful in obtaining a uniform scale. When some of the boats now under his supervision were first handed over to him, he noticed some severe cases of corrosion. After they had made another voyage he found in some the boilers were much improved, while in others they were not altered. In the latter he was therefore convinced the instructions had not been carried out; but subsequently with new engineers these boilers likewise improved, and were now in a healthy condition.

Free oxygen he was quite aware was an active agent in producing pitting and corrosion; but to whatever causes these evils might be attributed, he maintained that they could be kept under by careful

(Mr. Hallett.)
management. A piece of iron suspended in the feed-pipe would naturally be destroyed more quickly than a similar piece in the passage from the foot of the surface-condenser to the air-pump, for the simple reason that it would have to contend with much more friction.

The corrosion of compensating rings round manholes could certainly be prevented, if the precaution were taken to drain the boilers entirely out. Solid matter sank to the bottom, and this being the part where there was little or no circulation, the amount of solid matter contained in the water in that part would be far greater than Mr. Fothergill appeared to consider.

With the plan of leading the feed-water into the steam space he could not agree, as it induced priming. The method suggested in the paper of fitting the feed-pipe had the advantage of heating the water at the bottom of the boiler, and also of assisting the circulation. Having himself had a boiler fitted with the feed-pipe discharging into the steam space, he had for some time been unable to account for the priming, or for the packing wearing so quickly in the glands of the piston-rods and valve-rods that, after being under weigh for only forty-eight hours, it had been necessary to stop and re-pack; and that was not the only evil, for the bottoms of the boilers were quite cold. When the feed-pipe was altered to the method suggested in the paper, the temperature became uniform throughout the boilers, and the steam much drier.

From blowing the boilers down, if done as suggested in the paper, he had never experienced any ill effects. He knew of several boilers fourteen years old in which this system had been carried out, and they were still in good order. He should like to hear the results of the Admiralty experience.

An instance had been given by Mr. Marshall of boiler tubes corroding very quickly. One case had also come under his own notice, of a steamer making a voyage of a month's duration, and upon her return all the tubes had to be renewed; their failure was accounted for, through the ship having lain close to a chemical factory, and the boiler being filled with the water discharged therefrom.

The PRESIDENT said he was sure that the members would desire to present a vote of thanks to Mr. Hallett for his paper.

Mr. H. J. BAKEWELL, in compliance with the suggestion made by Mr. F. C. Marshall, appends the following remarks relative to Admiralty practice in the treatment of marine boilers, and the results that have been obtained to the present time.

In designing boilers for the navy, care is taken, so far as circumstances permit, to allow means of access to all parts for cleaning and examination; manholes are placed on the upper and lower parts, and the stays are arranged with due regard to spaces required for reaching the tubes and furnaces. Attention is also paid to placing the boilers on board in such position that the external parts are accessible for cleaning and painting at all times. The material of which boilers are made—now generally steel—is the best that can be obtained. The quality of the plates used is ensured by careful tests and continual inspection during the whole period of construction. After completion, whether kept in store or at once placed on board, new boilers are subject to supervision or to the treatment hereafter referred to.

The investigations of the Committee on Boilers served to show that the internal corrosion of boilers is greatly due to the combined action of air and sea-water when under steam, and when not under steam to the combined action of air and moisture, upon the unprotected surfaces of the metal. There are other deleterious influences at work, such as the corrosive action of fatty acids, the galvanic action of copper and brass, and the inequalities of temperature; these latter however are considered to be of minor importance.

Of the several methods recommended for protecting the internal surfaces of boilers, the three found most effectual are:—firstly, the

(Mr. H. J. Bakewell.)
formation of a thin layer of hard scale, deposited by working the boiler with sea water; secondly, the coating of the surfaces with a thin wash of Portland cement, particularly wherever there are any signs of decay; thirdly, the use of zinc slabs suspended in the water and steam spaces.

As to general treatment for the preservation of boilers in store or when laid up in the reserve, either of the two following methods is adopted, as may be found most suitable in particular cases. Firstly, the boilers are dried as much as possible by airing stoves; after which 2 to 3 cwt. of quicklime, according to the size of the boiler, is placed on suitable trays at the bottom of the boiler and on the tubes. The boiler is then closed, and made as air-tight as possible. Periodical inspection is made every six months, when if the lime be found slaked it is renewed. Secondly, the other method is to run the boilers up with sea or fresh water, having soda added to it; if ordinary crystal soda be used, the proportion is 1 lb. of soda to every 100 or 120 lbs. of water. The sufficiency of the saturation can be tested by introducing a piece of clean new iron, and leaving it in the boiler for ten or twelve hours; if it shows signs of rusting, more soda should be added. It is essential that the boilers be entirely filled, to the complete exclusion of air.

In cases where vessels in commission may have to remain in harbour for some considerable time, and when it is thought expedient to keep the boilers empty, the following plan is adopted. After the boilers have been well dried, one or two perforated trays or small braziers containing burning charcoal or coal are placed inside the lower manholes; after a while the trays are removed, and the boilers closed and made as air-tight as possible. The burning charcoal consumes the greater part of the oxygen within the boilers, and thereby prevents the oxidation of the plates and stays.

The working density of the water used in boilers is from $2\frac{1}{2}$ to 4 times the saltness of sea-water: a high density has been found beneficial in point of cleanliness.

It is considered advantageous to retain the water in boilers without change as long as possible, whether the fires are alight or not, and to remove it only when dirty, or when necessary for

cleaning or examination, the boilers being filled up quite full when not required for steaming.

With the view of ascertaining the condition of the water in boilers in respect of its acidity, neutrality, or alkalinity, it is the practice to test the water in each boiler with litmus paper once in twenty-four hours when the fires are alight, and once in seven days when they are not. Should the water be found in an acid condition, a small quantity of carbonate of soda is introduced with the feed-water to neutralise the acidity. The state of the water at each test is recorded.

Great care is taken to prevent sudden changes of temperature in boilers. Directions are given that steam shall not be raised rapidly, and that care shall be taken to avoid a rush of cold air through the tubes by too suddenly opening the smoke-box doors. The practice of emptying boilers by blowing out is also prohibited, except in cases of extreme urgency. As a rule the water is allowed to remain until it becomes cool, before the boilers are emptied.

Mineral oil has for many years been exclusively used for internal lubrication, with the view of avoiding the effects of fatty acid, as this oil does not readily decompose, and possesses no acid properties.

Of all the preservative methods adopted in H.M. service, the use of zinc properly distributed and fixed has been found the most effectual in saving the iron and steel surfaces from corrosion; and also in neutralising by its own deterioration the hurtful influences met with in water as ordinarily supplied to boilers. The zinc slabs now used in the navy boilers are 12 ins. long, 6 ins. wide, and $\frac{1}{2}$ inch thick, this size being found convenient for general application. The amount of zinc used in new boilers at present is one slab of the above size for every 20 I.H.P., or about one square foot of zinc surface to two square feet of grate surface. Consideration is now being given to the subject to see if this proportion of zinc can be reduced without detriment. Rolled zinc is found the most suitable for the purpose, and is now always issued for use. To make the zinc properly efficient as a protector, special care must be taken to ensure perfect metallic contact between the slabs and the stays or plates to which they are attached. The slabs should be placed in such

(Mr. H. J. Bakewell.)

positions that all the surfaces in the boiler shall be protected. Each slab should be periodically examined to see that its connection remains perfect, and to renew any that may have decayed; this examination is usually made at intervals not exceeding three months. Under ordinary circumstances of working, these zinc slabs may be expected to last in fit condition from sixty to ninety days, immersed in hot sea-water; but in new boilers they at first decay more rapidly. The slabs are generally secured by means of iron straps, 2 ins. wide and $\frac{3}{8}$ inch thick, and long enough to reach the nearest stay, to which the strap is firmly attached by screw bolts.

Great attention is paid to the cleanliness of boilers, and special instructions are in force for their periodical and thorough examination. The usual interval is three months, but other examinations are made within this time as opportunity offers, and according to the circumstances of working, at the discretion of the engineer in charge. Any signs of decay are noted in the engine-room register and reported to headquarters. All boilers are also subjected to periodical test by water-pressure to twice their working pressure. In the case of new boilers, or boilers repaired for four years' service, the water-test is applied after two years' service, and afterwards half-yearly. The results of such tests are reported to the Admiralty. In addition to these pressure-tests, boilers are occasionally tested by drilling the plates, to ascertain their thickness and the amount of decay if any has taken place.

With regard to the results of the present practice founded on the recommendations of the Boiler Committees, it may be said in general terms that, with proper observance of the regulations laid down for the guidance of engineer officers, corrosion in the boilers of the Royal Navy could hardly take place. At the present time reports of serious corrosion in boilers are of very rare occurrence.

The following half-dozen examples are quoted in illustration of the results of the approved treatment of boilers; they are taken promiscuously from recent reports, and may be said to represent fairly the current state of boilers in H.M. vessels. In the first three vessels the boilers were under Committee treatment from the time they were put on board:—

Name of Vessel.	Type of Boilers.	Age of Boilers.	Reported Condition of Boilers.
Carysfort	Admiralty low boilers.	6 years	Wear of 1-64th inch on plates, and of 1-32nd inch on tube-plates.
Champion		6 years	No wear.
Cleopatra	Do.	6 years	Wear of 1-32nd inch on bottom of combustion-chamber; no sign of wear elsewhere.
Iris	High boilers with tubes above furnaces.	7 years	No sign of wear.
Alexandra		9 years	Wear of 1-16th to 1-8th inch all over.
Amethyst		12 years	No sign of wear since 1881, when boilers were thoroughly repaired.

EXCURSIONS.*

On TUESDAY AFTERNOON, 5th August, after luncheon in the Cardiff Public Hall by invitation of the Local Committee, the Members visited, under the guidance of Mr. McConnochie, the Cardiff Docks and Coal-Shipping Machinery described in his paper (page 227), and witnessed the working of the new 25-ton movable hydraulic crane, with the anti-breakage telescopic hopper of Mr. Charles L. Hunter.

The opportunity was taken to visit the "Blue Jacket" steamer of Messrs. Hallett Brothers, loading with coal at No. 5 tip on the east side of Bute East Dock. She was built by Messrs. Joseph L. Thompson and Sons, Sunderland, her dimensions being 286 feet length, 36½ feet beam, and 24 feet depth, with a dead-weight capacity of 3100 tons. The boilers were open for inspection, in which Hannay's electrogen is used for preventing corrosion, as described in Mr. Hallett's paper (page 335); and the high-pressure cylinder was open, which had been running without direct lubrication. The engines are compound surface-condensing, of 1153 indicated H.P., having cylinders of 35 and 66 inches diameter with 42 inches stroke; they were built by Mr. John Dickinson, Sunderland, by whom the crank-shaft was built up of steel and wrought iron. Other fittings in the steamer are Cochrane's multitubular vertical donkey-boiler, Baxter's vertical capstan-windlass with compound frictional brakes and connections, Durham and Churchill's governors, and Laing's helical-wheel steam-steering gear. The boilers are also fitted with hydro-kineters, and their working pressure is 80 lbs. per square inch.

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* For their information respecting the routes followed in the Excursions, the Members were furnished with some interesting notes kindly prepared by the Honorary Local Secretary, Mr. T. Hurry Riches, of which use has here been made. The notices appended of the Collieries and Works visited were mostly supplied for the same purpose by the respective proprietors; while those of the Iron Works have been mainly derived from descriptions which appeared in *Engineering* about the time of the Meeting.

A railway truck was shown at the docks, fitted with Foulkes' continuous automatic railway brake.

From the docks a special train conveyed the Members to the new Locomotive Running Shed of the Taff Vale Railway at Cathays (page 243), over which they were conducted by Mr. Riches. Here was shown the small high-speed air-compressor described in his paper; and also Mayhew's automatic boiler-feeder at work on a stationary boiler.

In the evening the Members were entertained at Dinner in the Drill Hall, Cardiff, by invitation of the Most Honourable the Marquess of Bute; by whose kindness they were also invited to visit Cardiff Castle during the days of the Meeting.

A number of Works in Cardiff, of which a list is given on page 360, were opened to the visit of the Members on the afternoons of both Tuesday and Wednesday. Descriptions of various of these Works are appended (pages 360–367).

On Wednesday Afternoon, 6th August, after luncheon in the Cardiff Public Hall by invitation of the Local Committee, an Excursion was made by special train to four Collieries on the Taff Vale Railway, of which descriptions are appended (pages 369–374).

The route up to the collieries passed the recently restored Castell Coch (Red Castle); the old Nantgarw Pottery, where the now rare china of that name was produced; and the celebrated stone Bridge at Pontypridd, having a single arch of 140 feet span, built in 1755 by the self-taught mason and architect, William Edwards, after two previous attempts by himself in 1746 and 1751.

Returning past the ancient city of Llandaff with its cathedral, the Members visited the Penarth Dock (pages 367–9), which has recently been extended, though the new portion has not yet come into full operation. The depth of water varies from 23 to 39 feet. The Penarth Ship Slipway was opened in May 1879, and is capable of hauling up ships of 4000 to 5000 tons burthen.

After a trip in the Roads by steamer from Penarth pier head, landing at Penarth beach, the Members spent the evening in the Windsor Gardens, Penarth, overlooking the Bristol Channel, where they were entertained on the invitation of the Right Honourable Baron Windsor.

On Thursday, 7th August, an Excursion was made by special train to the Dowlais and the Cyfarthfa Iron Works. The route lay past the village of Caerphilly, with its fine old castle in ruins; at the south-east corner of the ruins is the celebrated leaning tower. Next are passed the large quarries of Pwllypant, from which are obtained almost the whole of the walling stones for the Roath Basin and Roath Dock, Cardiff. Arrived at Dowlais, the Members were received by the manager Mr. Edward P. Martin, under whose guidance they spent some hours in inspecting the extensive works (pages 374–7); where they were afterwards entertained at luncheon on the invitation of Mr. George T. Clark.

In proceeding thence in the afternoon by the new loop-line along the summit of the hills to Cyfarthfa, the old Morlais Castle ruins were seen standing out on one of the brows, looking like a heap or mound of masonry. Arriving in view of Cyfarthfa Castle, the seat of the Crawshay family, the Members were received at the Cyfarthfa Works by Mr. William Crawshay, and the manager Mr. William Jones, by whom they were conducted through all the departments (pages 377–380). The return journey down the valley to Cardiff led past the Merthyr Sewage Farm, Nixon's Merthyr Vale Colliery, and Pontypridd Bridge.

In the evening the Members were entertained at a Conversazione in the Free Library and Museum, Cardiff, by invitation of the Mayor, Robert Bird, Esq., and the Mayoress.

On Friday, 8th August, an Excursion was made by special train to the Rhymney and the Ebbw Vale Iron Works, the Abercarn Tin-Plate Works, and the Alexandra Dock at Newport. The route from Cardiff to Rhymney was past Caerphilly and Ystrad, giving a view of the Hengoed Stone Viaduct. On arrival at the Rhymney Iron Works the Members were received by the manager Mr. David Evans, and the engineer Mr. John R. Williams, who conducted them through the works (pages 381–6).

From Rhymney the train proceeded up the incline to the head of the Rhymney Valley, eastwards along the hill tops, and down Ebbw Vale to the Ebbw Vale Works (pages 386–392). Here the Members were received and conducted through the works by the chairman Mr. Edward Coward, and the manager Mr. Calvert B. Holland; and were afterwards entertained at luncheon by invitation of the Ebbw Vale Company.

In the afternoon, proceeding down the valley and passing under the celebrated Crumlin Viaduct to Abercarn, the Members visited the Tin-Plate Works (page 392) of Mr. Daniel Whitehouse, where they were received by himself.

Thence they were taken on to Newport, where they were received at the Alexandra Dock (pages 392–4) by the engineer Mr. Wm. Stopford Smyth, and the secretary Mr. J. S. Adam. Other Works in Newport were also open to the visit of the Members, descriptions of which are appended (pages 394–5).

In the evening on returning to Cardiff the Members were entertained at Dinner in the Cardiff Public Hall by the Patent Nut and Bolt Company, as representatives of Newport.

On Saturday, 9th August, an Excursion was made by special train to the Severn Tunnel Works, near Portskewett, where the Members were received and conducted through the works and the tunnel by the contractor Mr. Thomas A. Walker, and his staff (pages 395–7). They were afterwards entertained at luncheon at the works on the invitation of Mr. Walker.

WORKS IN CARDIFF
OPENED TO THE VISIT OF THE MEMBERS.

Bute Docks.
Bute Gridiron.
Cardiff Junction Dry Dock and Engineering Works.
Dumfries Ship-Repairing and Engineering Works.
Bute Dry Dock, Shipbuilding, and Engineering Works.
Wallsend Slipway and Engineering Works.
Tyneside Engine Works.
Hills' Dry Docks and Engineering Works.
Mountstuart Shipbuilding, Graving Docks, and Engineering Works.
Rhymney Railway Locomotive Shops.
Taff Vale Railway Locomotive Shops, Running Shed, and Carriage and Wagon Works.
Lloyd's Bute Proving House.
Cardiff Rope Works, Grangetown.
Tharsis Sulphur and Copper Works.
Cardiff old Gas Works and Grangetown Gas Works.
Bute Gas Works.
Vaughan's Steam Dyeing and Laundry Works, Canton.
Hopkins' Steam Bakery.
Waring's Adamsdown Fire-Brick Works.
Heigham and Co.'s Paint Works.
South Wales Daily News Printing Works.
Western Mail Printing Works.
Penarth Dock and Ship Slipway.

BUTE SHIPBUILDING AND ENGINEERING WORKS.

Situated between the River Taff and the Glamorganshire Canal. The forge is adapted for the heaviest work required in shipbuilding and repairing; adjacent are fitters', smiths', boilermakers', plumbers', and pattern-makers' shops, and foundry. In the centre of the yard is a boat-building shop and store, with carpenters' and joiners' shops overhead. A locomotive steam-crane is employed, capable of lifting $7\frac{1}{2}$ tons. Two hopper-barges, each of 300 tons dead-weight capacity, were recently launched from the yard, for use in connection with the dredgers that keep the channel open to the entrances of the Bute Docks. At the time of the Members' visit, a screw steamer built

entirely of Landore steel was on the stocks, nearly completed, 240 ft. long by 33 ft. broad and 18 ft. deep, with a dead-weight capacity of 2000 tons. There was also just commenced the caisson of 87 ft. length, 16 ft. width, and 29 ft. depth, which will be used for subdividing into two lengths the new Bute dry dock belonging to this company, now in course of construction at the southern corner of the Roath Basin, as described in Mr. McConnochie's paper (page 238). The iron gates for this new dock were also built at these works.

WALLSEND SLIPWAY AND ENGINEERING WORKS.

These works were opened on 1st July 1884, and cover about an acre of ground between the public graving dock (page 233) and the new Roath dock now in course of construction (page 227). The lofty main building, 150 ft. long and 67 ft. wide, constitutes the erecting and machine shop, containing several fine new tools, which are driven by Kirkstall cold-rolled shafting. A 25-ton overhead travelling crane, driven by a square shaft, commands the shop, and runs over the railway siding which passes across at one end. There is no steam engine on the premises, the motive power being obtained from one of Crossley's 16-H.P. gas engines, supplied by Dowson's gas apparatus using anthracite coal. A gallery over the smaller machine-tools is occupied for pattern-making and wood-working. The plant for boiler-making and for repairing iron ships is temporarily in the main building, pending the erection of a similar building adjoining. In the yard are a plate-heating furnace and a beam-bending machine. Another building, 113 ft. long and 45 ft. wide, forms the foundry, containing plant specially designed for casting large propellers; part of this shop is at present used as a smithy.

TYNESIDE ENGINE WORKS.

These works, which were opened in January 1884, are situated near the public graving dock (page 233), and have an area of about an acre. They employ some 250 workmen, who are mostly occupied outside the works, executing repairs on board of steamers in the docks.

The buildings are lofty, light, and substantial, and the tools new and of recent design. A railway siding runs through the premises. The erecting shop has a 10-ton overhead travelling crane. In the machine shop are the usual tools for ship-repairing, the fitters' benches and light machines being in a gallery. Adjoining are the coppersmiths' shop and the brass foundry. The pattern shop and carpenters' shop, with the usual wood-working machinery, are on the upper floors of a boat-building shop. The smiths' shop with steam hammer is near the boiler shop, which contains an overhead travelling crane to lift 35 tons, steam and hydraulic boiler-making machinery, and a large sunken fire for welding up stern-frames and similar heavy work. In the yard are heating furnaces for plates and angle-iron frames, with plate-levelling blocks.

HILLS' DRY DOCKS AND ENGINEERING WORKS.

These works were established in 1857 for the building, and more especially the repairing, of iron or wood vessels. There is a graving dock at the head of the Bute West Dock, 230 ft. long by 40 ft. wide, with 12½ ft. of water over the sill, and so arranged as to be capable of taking in at the same time two vessels of 150 ft. and 135 ft. length. But the chief premises are at the north-west side of the Bute East Dock, opposite the masting shears, near the ballast wharf, adjoining the coal tips, and comprising about four acres. Here there are two graving docks side by side, one being 408 ft. long and 48 ft. wide at the entrance ; the other, recently constructed, is 400 ft. long and 40 ft. wide at entrance ; each has 18½ ft. of water over the sill. Between the two docks are laid rails, on which is a travelling crane capable of lifting 10 tons from either dock. The pumping apparatus, by Messrs. W. H. Allen and Co. of London, is very effectively arranged, so as to be available for either dock, and able to dry a ship in 1½ hours (page 236). The iron caissons are also of original construction. As tides have not to be considered, vessels can be docked and undocked with rapidity and perfect safety at all hours, without risk or loss of time. Here also is the engineering establishment, with foundry and fitting shop, supplied with the most

modern machinery; and ranges of sheds with all appliances for iron ship building. The whole establishment is conveniently arranged, and is in immediate connection with the general railway system.

MOUNTSTUART SHIPBUILDING, GRAVING DOCKS, AND ENGINEERING WORKS.

No. 1 dock is 324 ft. long by 70 ft. wide, with entrance gates 45 ft. wide, and 20 ft. depth of water on the sill and keel-blocks at ordinary spring tides. No. 2 dock is 420 ft. long by 105 ft. wide, with entrance gates 52 ft. wide, and 26 ft. depth of water on sill and keel-blocks at ordinary spring tides; it has also inner gates, which retain 20 ft. depth of water on the keel-blocks. In this dock two vessels, each 360 ft. long, can be accommodated alongside each other. In the event of the dock being required for a vessel exceeding 360 ft., a middle row of blocks can be utilised to take a ship of 420 ft. length. To the west and north of the graving docks are the brass and iron foundries, saw mills, coppersmiths', joiners', pattern-makers', and boiler shops, smithy, forge, and engineering shops. In the smithy are two large ground fires, capable of heating large forgings such as keels and stern-frames. Whilst undergoing repairs which do not necessitate the use of a dry dock, ships lie alongside the yard on the mud in perfect safety. Extension of the premises is intended. A railway siding runs into the yard.

TAFF VALE RAILWAY LOCOMOTIVE SHOPS.

The locomotive and repairing shops of the Taff Vale Railway are situated close to the Bute Docks. The erecting shop is in the middle of the yard, and contains eleven pits; and there is room also for four boilers to come in for having their mountings fitted on. Under a lean-to roof seven other boilers can also be fitted. Thus eleven boilers can be prepared and eleven engines erected at the same time. The pits lie across the shop; and there are traversers at each end of the shop, running the entire length. Over any pit can also be placed a portable gantry, driven by belt from the shop shafting. Around the yard are various machine-shops, with the

necessary tools for turning out locomotive and hydraulic work, a good deal of the latter being for use at Penarth dock and harbour, for the hydraulic cranes and coal machinery. A tube-drawing apparatus is used for working up old brass boiler-tubes that have become defective at the ends, instead of cutting the ends off and piecing them; the tube is drawn cold through a pair of dies tapering slightly smaller than the tube; the diameter of the tube is thereby very slightly diminished but the thickness is rather increased, and the length is increased sufficiently to allow of cutting off the defective end. In the yard is a gas furnace for heating tyres by means of two semicircular gas and air pipes pierced with holes. In the boiler shop are hydraulic riveters with compound accumulator: the stationary machine has a 7 ft. gap, so as to rivet up a whole boiler-barrel, and it will also take in work 20 ins. wide for girders; the portable machine is for riveting foundation and fire-hole rings. In the smiths' shop are two small steam hammers, and two of Allen's steam strikers, which latter have to a great extent superseded the spring oliver previously used.

LLOYD'S BUTE PROVING HOUSE.

Contains two powerful hydraulic machines, which indicate the strains applied by levers and dead weights. The breaking machine tests up to 250 tons, and is fitted with duplex hydraulic gauges, one of which indicates from 1 lb. to 6000 lbs. per sq. inch, and the other from 1 lb. to 1000 lbs., for experimental and light testing. The tensile machine, the bed of which is 15 fathoms long, tests up to 180 tons. The hydraulic shears are capable of exerting a force of 250 tons, and are fitted with gauges to indicate the pressure applied in shearing iron and other metals cold. In addition to the ordinary testing of chain-cables and anchors, experimental testing of iron, steel, wood, concrete, &c., is also carried out. On the occasion of the visit of the Members on Wednesday afternoon, 6th August, the following tensile tests were made by the superintendent, Mr. George W. Penn, upon three samples from a round iron bar rolled from blooms made of scrap iron. The first sample, tested with the skin on, was 1·56 inch diameter, and broke at a total load of 43·20 tons,

equivalent to 22·61 tons per square inch, with a good fracture, fine and fibrous; its diameter at the fracture was 1·18 inch, showing 42·9 per cent. contraction in area; and the elongation in 10 inches was 25·8 per cent. The second sample, tested with the skin on, but welded, was 1·53 inch diameter, and broke across the weld at 40·50 tons load, equal to 22·12 tons per square inch, showing a good fibrous fracture with a few crystals; the diameter at the fracture was 1·38 inch, being 18·6 per cent. contraction in area; and the elongation in 10 inches was 14·0 per cent. The third sample had the skin turned off down to 0·872 inch diameter for a length of 6 inches, and broke in the reduced part at 13·75 tons load, equal to 23·03 tons per square inch, with a good fibrous fracture; the diameter at the fracture was 0·656 inch, showing 43·5 per cent. contraction of area; and the elongation in the 6 inches was 37·5 per cent. A sample of round BBH bar iron of 3 inches diameter was sheared at 20·78 tons per square inch with a good clean cut. Drawings were exhibited of nine anchors which had been tested to destruction, showing the fractures as they took place in testing.

CARDIFF ROPE WORKS, GRANGETOWN.

These works, belonging to Messrs. Joseph Elliott and Sons, were erected in 1875, and rebuilt in 1879, after being almost entirely destroyed by fire. They comprise a large mill in which the preparation and spinning of Manilla and Europe hemp rope are carried on. The machinery is of the newest and best style, the latest additions being two spinning machines by Messrs. Lawson and Sons of Leeds, which turn out the most perfect yarn it has hitherto been possible to spin. From this mill the yarn is passed over to the rope-laying department, where the machines have a travel of about 1200 feet, all covered in by a corrugated iron roof extending from a warehouse 200 ft. by 30 ft. The machinery is capable of making from the very smallest to the largest rope a ship may require; the largest yet made was a 13-inch Manilla rope 120 fathoms long, which was made up in less than eight hours. Owing to the complete and convenient arrangement of all the appliances in the works, the greatest economy of labour is carried out. Upwards of 30 hands are

regularly employed, and the works are capable of manufacturing about 10 tons per week. Arrangements are now being made to erect machinery for the manufacture of steel-wire rope, to meet the increasing demand for this class of rope both for steam-ships and for collieries.

THARSIS SULPHUR AND COPPER WORKS.

Started in 1874, these works are the sixth which have been erected in this country by the Tharsis Sulphur and Copper Company, for the treatment by the "wet process" of burnt pyrites, being the residues from the mineral imported from the Spanish mines worked by the company, from which copper, lead, silver, gold, and also purple ore or "blue billy," are produced. The works employ some 200 men, and occupy about 30 acres, of which about 11½ acres are under cover.

CARDIFF GAS LIGHT AND COKE WORKS.

Incorporated in 1837, and now employing 250 men at the two stations, the combined area of which is about 12 acres; the old station is near the head of the Bute West Dock, and the new works are at Grangetown.

BUTE GAS WORKS.

These works are the property of the Marquess of Bute, erected in 1871 for supplying gas to the Bute Docks, which at that time required fourteen million cubic feet annually, but at the present time require thirty million cubic feet annually. The plant is of modern type, consisting of six retort benches, each containing seven clay retorts, 21 ins. by 15 ins., Paddon's condensers, Anderson's exhauster and scrubber, and a set of four purifiers, each 16 ft. by 8 ft., worked by one of Cockey's dry-faced centre-valves; vertical engine and two Cornish boilers; Wright's station meter; gas-holder of 75,000 cub. ft. capacity.

STEAM DYEING AND LAUNDRY WORKS, CANTON.

These works, belonging to Messrs. W. E. Vaughan and Co., comprise about 17,000 sq. feet of covered floorage, and employ 98

hands, 24 males and 74 females. The machinery consists of four steam-power washing machines; chemical cleaning, merino-finishing, carpet-cleaning, ironing, calendering, glazing, wringing, and starching machines; box mangle, hydro-extractors, logwood-extractor, finishing cylinders, presses, and frames.

STEAM BAKERY.

Built in 1879 by the proprietor, Mr. George Hopkins, and covers half an acre of land. It contains three ovens of the ordinary pattern; and one of novel design, heated by Perkins' steam-pipes for continuous working and maintaining a uniform temperature. In this oven the floor, sides, and arched roof are lined with plain straight wrought-iron tubes, slightly inclined to the horizontal, with their lower ends projecting outwards into the furnace outside the back of the oven. The tubes are welded up at both ends, after each has been partly filled with water, by which the heat from the fire is conveyed into the oven and diffused equably throughout. The bakery is also fitted with various labour-saving machines for all processes in the making of cake and bread: including belts for carrying the loaves from the ovens to the packing and sale rooms, and for returning the empty tins. A cylindrical fruit-cleaner of centrifugal action, capable of cleaning one ton per day, is driven by a steam engine; the other various machines in the factory are driven by an Otto gas-engine of six horse-power. The bakery is capable of turning out three thousand 4 lb. bread loaves and ten tons of cake weekly; forty hands are employed.

PENARTH DOCK AND TIDAL HARBOUR.

The Penarth Dock and Basin are situated in a line with each other on the south bank of the mouth of the River Ely. There is also a tidal harbour at Penarth, formed by the lower part of the River Ely, which is provided with staiths for the shipment of coal on its northern bank. The Penarth Dock and Harbour original works were designed by Sir John Hawkshaw, and carried out under his supervision and that of Mr. Samuel Dobson. The dock extension recently completed was designed and carried out by Sir John

Hawkshaw and Mr. George Fisher, Mr. H. Oakden Fisher being the resident engineer.

Penarth Dock.—The dimensions of the dock are as follows:—length, 2900 ft.; width, 370 ft.; area, 23 acres. The basin is 400 ft. long by 330 ft. wide, and its area is 3 acres. The lock is 270 ft. long and 60 ft. wide. The sea entrance also is 60 ft. in width. On the sill of the sea-gates and the lock-gates the depth of water is 35 ft. at ordinary spring tides, and 25 ft. at neap tides. Being a tidal dock, at high water the gates can be opened from sea to dock, allowing immediate ingress and egress of ships, thus preventing the delay so often complained of in the shipment of minerals at other ports.

There are fourteen coal-tips now constructed on the south side of the dock, and two in the basin. They are each capable of shipping 150 tons per hour. All of these tips are on the high level, worked by hydraulic and counterbalance machinery. The coal trucks are worked on and off the tips by gravitation. One of the tips in the dock and the tip in the basin are twin tips; that is to say, the loading of coal into the same vessel is intended to be effected by means of two tips simultaneously, and vessels loading at the twin tips can be loaded at the rate of 300 tons per hour. The dock being constructed on a curve enables the coal tips, built on jetties, to project one beyond another; thus the longest ships load without interference by reason of their overlapping each other.

On the north side of the dock there are ten hydraulic and steam cranes, for discharging iron ore, ballast, &c., five of which are portable, and a 10-ton lifting crane, with the necessary sidings for working them. Two of these cranes have been so placed that they will work into the same vessel at the same time. This double arrangement and the twin tips have been specially provided to give despatch to steamers. Very powerful hydraulic machinery has been provided, by which are worked the ballast and ore cranes, as well as the machinery for opening and closing the gates, the sluice machines, capstans, fender-chain machines, &c. There are about 28 miles of sidings connected with this dock, for storing wagons for the convenience of merchants.

Penarth Tidal Harbour.—Length measuring along the centre of the river, 13,000 ft.; frontage on Cardiff side, 12,000 ft.; on Penarth side, 12,700 ft.; total frontage, 24,700 ft. Average width at water line at high water for first reach of river, 600 ft.; length, 4,000 ft.; area, 55 acres. Average width at water line in same reach when depth of water is 15 ft., 280 ft.; area, 26 acres. Number of staiths for the shipment of coal, thirteen; room for six more; each staith capable of shipping 150 tons an hour. Depth of water in the berths at high water at ordinary spring tides, 30 ft.; and at ordinary neap tides, 20 feet. Vessels up to 800 tons burthen take the ground, and are loaded with safety and despatch in this harbour. The maximum run of the tide is at the rate of about 2 knots an hour. Three cranes for unloading ballast and iron-ore, each capable of unloading 50 tons an hour. A large wharf is in course of erection, upon which will be placed three more portable hydraulic cranes for unloading iron-ore and ballast.

GREAT WESTERN COLLIERY.

This Colliery, situated at Gyfeillon, near Pontypridd, has two shafts for winding only, and one for pumping only.

Winding.—No. 1 or the Hetty pit is 16 ft. diameter and 400 yards deep, being sunk to the 6 ft. seam; but it is now working the 4 ft. seam of steam coal, which is met with at a depth of 365 yards. The output is about 1200 tons per day. The winding engines have horizontal cylinders 40 ins. diameter and 6 ft. stroke, fitted with Stevens' automatic expansion gear. The rope-drums are 16 ft. diameter, winding flat ropes. No. 2 pit is oval, 14 ft. 4 ins. by 10 ft. 9 ins., and 430 yards deep, working the red coal, which is a seam of high quality steam-coal. The output is about 300 tons per day. The winding engines have horizontal cylinders 30 ins. diameter and 4 ft. stroke. The rope-drums are 11 ft. diameter, winding flat ropes. Electric signals are used in both the pits.

Ventilation.—Guibal fan of 40 ft. diameter, driven direct at 52 revs. per min. by an engine with cylinder of 36 ins. diameter and 3 ft. stroke; a second similar engine is in reserve. A Schiele fan is now being erected. No. 1 is the downcast pit, and No. 2 the upcast.

Underground Haulage by Compressed Air.—The air-compressor, constructed by Messrs. Daniel Adamson and Co., has two steam cylinders of 40 ins. diameter, and air cylinders of 42 ins. diameter, with 6 ft. stroke. The compressed air works the following Stevens' underground engines, constructed at the Uskside Iron Works, Newport:—one hauling engine, having a pair of 14-inch cylinders with 18 inches stroke; and three hauling engines, each having a pair of 8-inch cylinders with 12 inches stroke. These hauling engines are all in No. 1 pit, where the working faces are at an average distance of about 1000 yards from the shaft; the roads are straight, and the gradients so easy that an engine is required at the foot of the incline to overhaul the rope. In No. 2 pit the haulage is done by horses, the workings being near the shaft. Steam is supplied to the air compressor from four boilers, which are fired by the waste gases from fifty Coppée coke ovens. One of Sheppard's three-tank coal-washing machines is used for washing the coal for coking, and turns out 200 tons per day.

Pumping.—One pump with a single-acting 4-inch ram of 6 inches stroke is sufficient for raising all the water met with in the colliery.

LEWIS' MERTHYR COLLIERY.

At this colliery, situated at Havod in the Rhondda Valley, of which the engineering manager is Mr. William Thos. Rees, there are three pits:—the Bertie and the Havod, on opposite sides of the valley, each working the upper 4 ft. seam of steam coal at a depth of 360 yards; and the Coedcae pit on the same side as the Bertie, working the No. 3 seam of bituminous coal at 120 yards depth.

At the Bertie pit the winding machinery consists of a pair of horizontal 42-inch cylinders with 7 ft. stroke, working a spiral drum of 15 to 30 ft. diameter, the whole constructed by Messrs. John Fowler and Co., Leeds. The pulley-frame is of wrought iron. The output averages 1100 tons per day. A Schiele fan of 13½ ft. diameter, constructed by the Union Engineering Co. of Manchester, produces the ventilation; it is driven by a belt from an engine with 24-inch cylinder, a duplicate engine being in reserve; the engine pulley, making 55 to 60 revs. per min., is 17 ft. diameter,

and the fan pulley is 6 ft. 2 ins. diameter; the water-gauge in the fan drift averages 2·2 ins., and the ventilation produced is over 200,000 cubic feet per minute.

The Havod pit has a horizontal winding engine with 30-inch cylinders and 6 ft. stroke, and drum 12 ft. diameter with round ropes. The output averages 680 tons per day. A Waddle fan of 40 ft. diameter, driven by an engine with 30-inch cylinder, produces the ventilation; it is estimated to be capable of delivering 150,000 cubic feet of air per minute.

At the Coedcae pit the winding engine has a pair of 24-inch cylinders with 4 ft. stroke; the drum is 12 ft. diameter, winding flat ropes. The output averages 280 tons per day. The underground haulage is on the tail-rope system, and the distance is one mile; it is done by a steam engine with 14-inch cylinders and 16-inch stroke, which with its boilers is placed close to the bottom of the upcast shaft. Furnace ventilation is used, and naked lights in the workings.

There are 111 coke ovens of ordinary type, to which Sheppard's coal-washing machine and crushers supply 200 tons per day. The waste heat and gases from the coke ovens are utilised for raising steam in eight Lancashire boilers of 6½ ft. diameter and 36 ft. length, under which no coal is consumed.

CYMMER COLLIERY.

This colliery is situated close to Porth in the Rhondda Valley, and belongs to Messrs. George Insole and Son, the manager being Mr. Thomas Griffiths. There are three pits, two of which, the Old and the New, are 400 yards deep, and are sunk to the 9 ft. seam of steam coal, underlying the celebrated 4 ft. seam. The long-wall system of working is followed, and the average output is 1300 tons of steam coal per day, chiefly from the 4 ft. seam. The third pit yields bituminous coal for household use.

At the Old pit, which is the upcast, the winding is done by a pair of horizontal engines with 28-inch cylinders of 4 ft. stroke, working a drum of 11 ft. diameter with round ropes; the height of the head gear over the shaft is 60 ft., and the pulleys are 12 ft. diameter.

The New pit, which is the downcast, has a pair of horizontal winding engines constructed by Messrs. Harvey of Hayle; the cylinders are 42 ins. diameter by 6½ ft. stroke, and are fitted with automatic expansion gear which has saved one boiler out of eight. The winding drum is 17 ft. diameter, and flat ropes are used; the head gear over the shaft is 75 ft. high, and the pulleys are 17 ft. diameter. The coal is weighed and screened on an iron heapstead, 144 ft. long and 44 ft. wide, erected over the pit mouth. The cages are loaded and unloaded by Fisher's steam banking apparatus, which elevates the rails so that the empty tram runs by gravity into the cage and helps to push the full tram out. Beneath the heapstead is Sheppard's coal-washing machine with crushers, capable of washing 200 tons per day.

The ventilation is effected by a Waddle fan of 45 ft. diameter, driven by a 32-inch cylinder of 4 ft. stroke, and producing a current of 250,000 cubic feet of air per minute, with a water-gauge of 3 inches in the fan drift and 2 inches at the separation doors underground.

For underground haulage there is a pair of horizontal engines at surface, with 20-inch cylinders of 3½ ft. stroke, geared 6 to 1 to two pairs of grooved drums, one pair 10 ft. diameter and the other pair 5 ft. The ropes from the drums pass down the pit, and haul independently from three separate districts on the endless-rope system at a speed of 2½ miles per hour.

A small gas-works at surface is supplied by a blower of gas, which is conveyed up the shaft by pipes and is forced by a steam injector into the purifiers. Another injector forces the purified gas down the pit for lighting the workings; and the water from the injector steam is separated from the gas in a receiver placed at the pit bottom.

LLWYNYPIA COLLIERY.

Of this Colliery, belonging to the Glamorgan Coal Co., and situated about the centre of the Rhondda Valley, the manager is Mr. W. W. Hood. There are three shafts used for drawing coal. Pits Nos. 2 and 6 are set apart entirely for winning the lower or

steam-coal measures, and No. 3 pit for the upper or bituminous measures. The total quantity of coal drawn per day is about 1600 tons.

No. 2 pit is 372 yards deep. The winding engines have cylinders 34 ins. diameter with 5½ ft. stroke, and a spiral drum 15 ft. and 25 ft. diameter. The cages are double-decked, and draw two trams at a time; the total weight, including coal, trams, and cage, is about 5½ tons. Underground there are two pairs of hauling engines, driven by steam, each having cylinders 18 ins. diameter with 3 ft. stroke; and the drums are 6 ft. diameter, geared 3 to 1. One of these engines draws coal from a distance of 1600 yards along a very undulating road; the other from a distance of about 1100 yards along a more regular gradient, down which the load descends throughout the whole distance. The sidings at the bottom of the pit are worked by endless-rope haulage, which is driven by an engine having a cylinder 14 ins. diameter with 3 ft. stroke; one of Fowler's clip-pulleys is used, of 4 ft. diameter.

No. 6 pit is 403 yards deep. The winding engines have cylinders 30 ins. diameter with 5 ft. stroke, and 14-ft. drum; but here the load is only about half that at the other pit. Underground there are two hauling engines, each driven by compressed air, and of much smaller dimensions than those in No. 2 pit.

No. 3 pit is only 108 yards deep. The winding engines are of the diagonal type, the cylinders being 15 ins. diameter, geared 3 to 1; the drum is 8 ft. diameter. At this pit there is only one hauling engine, which is situated at the surface, and works two separate planes underground by the main-and-tail-rope system.

A 15-ft. Schiele fan placed at No. 6 pit ventilates all the workings of the colliery. It is driven direct at 140 to 145 revs. per min. by a horizontal engine having a cylinder 21 ins. diameter with 21 ins. stroke. The total current of air produced is about 200,000 cubic feet per minute, with a water gauge of 1½ inch.

The compressed air for working the underground hauling engines in No. 6 pit is supplied by a pair of air-compressors having steam cylinders 26 ins. diameter and 4 ft. stroke, and air cylinders 24 ins. diameter.

Two pumping engines made by Messrs. Hathorn Davey and Co. are placed at the bottom of No. 4 pit, which is entirely set apart for pumping the water from the upper measures. The quantity of water to be dealt with seldom exceeds 400 gallons per minute.

There are over 300 coke ovens of the ordinary Welsh type, 12 ft. long and 6 ft. wide by 5½ ft. high; each produces about 6 tons of coke per week. They are all charged at the top; and endless-rope haulage is used throughout for drawing the coal from pit-bank to ovens. The batches are always watered in the ovens; and small steam travelling cranes are used for drawing them after coking.

DOWLAIS IRON WORKS.

These extensive works were founded nearly 140 years ago, and are in many respects noteworthy as having been connected with several important epochs in the iron and steel industry of South Wales. Here the first steel rail ever made was rolled, the mill from which it was turned out being in active work at the present time. Dowlais is also historically interesting as having been connected with the earliest history of the locomotive. Scattered over a vast area of ground, the works are at present on the eve of many and great changes, which will have the effect of transforming their whole aspect.

At the southern end are the steel works. There are three Bessemer pits, each of which has two 8-ton converters. The ladle with the metal is brought in from the furnaces at the back of the converters at a level somewhat above that of the pits, and is raised by a hydraulic lift to a higher level for tapping into the converters. There are two cupolas for spiegel at the back of each pit, placed high enough for the spiegel to flow into the converters. There are four cupolas for melting pig when required. For blowing the converters there is a pair of horizontal engines by Messrs. Hick Hargreaves and Co., having 36-inch steam cylinders and 48-inch air cylinders, the stroke being 5 ft. These are the original engines erected in this part of the works for steel making; and in addition to them there is a pair of vertical engines by Messrs. Daniel Adamson and Co., with 40-inch steam cylinders, 54-inch air cylinders, and a stroke of 5 ft. There are three pairs of Siemens-Martin steel

furnaces, which take respectively 6, 7, and 8-ton charges; each pair of furnaces is in connection with a pit, which is arranged in the same way as the Bessemer pits. The hydraulic machinery for both the Bessemer and Siemens plant is situated in the same building. It consists of four pairs of pumping engines, namely a pair of 10 inch by 12 inch, a pair of 12 inch by 24 inch, a pair of 16 inch by 24 inch, and a pair of 14 inch by 30 inch engines. Near them there is also a beam blowing-engine, with 36-inch steam cylinder and 7 ft. stroke, which is used for blowing converters when they are being warmed. There are also three Roots' blowers for serving the cupolas. Steam is supplied by nineteen single and double-flue boilers, fired with coal.

The ingots are taken hot from the moulds to the cogging mills, by means of iron trolleys which hold six or eight ingots each. The original cogging-mill engine is by Messrs. Kitson and Co.; it is geared four to one, and has two cylinders, each 30 ins. diameter by 4 ft. stroke. The rolls are 36 ins. between centres, the top rolls being movable. The blooms are sheared into lengths by a pair of horizontal sliding shears, and then lifted on bogies by a hydraulic crane, to be taken to the rolling mill. In the second cogging mill the rolls are 36 ins. diameter, and are driven by a double pair of compound horizontal tandem engines by Messrs. Kitson and Co., geared three to one; these are fitted with piston valves, and have cylinders 24 ins. and 43 ins. diameter, the stroke being 4 ft. The carrying rollers to this train are placed very close together, and are driven by a continuous train of spur-wheel gearing. There are four heating furnaces fired by gas, and thirteen in which coal is used; most of these have steam boilers attached. For serving all the furnaces, four blocks of gas-producers are provided, each block having twelve fires.

The rail mills have a train with 25-inch centres, driven direct by a pair of horizontal engines by Messrs. Kitson and Co., with cylinders 48 ins. diameter by 4½ ft. stroke. Here there are ten heating furnaces, all fired with coal, from which the blooms are drawn by hydraulic power. From the mill train the rails are travelled on carrying rollers in the usual way to a swinging circular saw, and

then to the straightening presses. There are eight rail-ending machines, driven by separate engines, for the purpose of cutting rails to exact length; and eight horizontal rail-drills, driven by a semi-portable engine.

A new rail-mill is being laid down, for which the engines by Messrs. Kitson and Co. are in course of erection; they have 60-inch cylinders and 5 ft. stroke, and will be coupled direct to a 25-inch train. In these, as in the other engines, the reversing is effected by hydraulic power. In the centre of this mill there stands an old beam-engine which drove the rolls for many years.

In the principal part of the works there are now six furnaces in blast, of various sizes from 50 ft. to 60 ft. high. No. 1 is cylindrical, 60 ft. high, and hooped with iron bands; the diameter at the boshes is $17\frac{1}{2}$ ft., at the hearth $7\frac{1}{2}$ ft., and at the throat $12\frac{1}{2}$ ft. Attached to it are three Cowper stoves, 22 ft. diameter and 60 ft. high, two serving the furnace whilst the third is being heated. Close to this, a new furnace of similar style is being erected, of the same diameter but 10 ft. higher. No. 9 furnace, of the same dimensions as No. 1, has the blast heated by three Whitwell stoves, two delivering blast whilst the third is being heated. The other furnaces in blast are of smaller dimensions and fitted with pipe stoves. The blowing engines are placed in various buildings. The first is of the ordinary beam type, having a steam cylinder 55 ins. diameter and 13 ft. stroke, and an air cylinder 144 ins. diameter and 12 ft. stroke. The second and third engines are also of the beam type, working independently of each other. Their steam cylinders are 60 ins. diameter with 10 ft. stroke, and their air cylinders 132 ins. diameter with 9 ft. stroke. The fourth engine is an old low-pressure condensing beam-engine, with double-beat valves worked by tappet gear; the steam cylinder is 60 ins. diameter, the air cylinder 96 ins., and the stroke 8 ft. The fifth is a compound non-condensing beam-engine with cylinders 42 ins. and 60 ins. diameter, air cylinder 144 ins. diameter, and stroke 10 ft. The sixth is a beam-engine with 45-inch steam cylinder and 104-inch air cylinder, the stroke being 9 ft. These engines all deliver into one main, the pressure of blast being about $3\frac{1}{2}$ lbs. per sq. inch. They are driven principally by boilers fired by

the waste gases from the furnaces and coke ovens, only a small quantity of coal being burnt for raising steam. On the high ground at the back of the furnaces are stored the materials, which are raised to the additional height of the more modern furnaces by steam hoists with overhead cylinders connected direct.

In addition to extensive ranges of coke ovens of the ordinary South Wales type, situated on the high ground at the back of the furnaces, there are two blocks of Coppée ovens, each containing 36 ovens, which are served by two steam pushers-out. Coal-washing machinery has recently been fitted up by M. Evence Coppée of Brussels, worked by a horizontal engine with a 30-inch cylinder and 5 ft. stroke; it is intended for treating at one operation both bituminous coal and harder varieties.

At the Ivor Works, forming the northern portion of the premises, there are four furnaces in blast, and one out, making iron for the rolling mills. One of them is 65 ft. high, and is served by Whitwell stoves, the others having the old cast-iron pipe-stoves. There are two blowing engines, one having a steam cylinder of 52 ins. diameter, and air cylinder of 144 ins., with 9 ft. stroke; the other is a horizontal engine, with steam cylinder 52 ins. diameter, air cylinder 108 ins., and 9 ft. stroke. There are two puddling forges and one plate-mill, together with guide and merchant-bar mills.

CYFARTHFA IRON WORKS.

These works are of great antiquity, dating back to the earliest days of the South Wales iron industry. One of the blast-furnaces bears the date 1765, though rebuilt in 1827. The tops of the old blast-furnaces now serve as a platform, from which the materials are raised a height of 20 ft. to the tops of the new furnaces by means of carriages running up an inclined plane, and worked by a winding engine at the hearth level below; this lift is designed to supply four furnaces, of which at present three only are built.

These new blast-furnaces are of the latest build, having been completed within the last three months. They are 70 ft. high from hearth to charging plate, iron-cased and close-topped. The diameter

at the top is 12 ft., at the boshes 17½ ft., and across the hearth 7½ ft. The internal capacity of each is between 11,000 and 12,000 cubic feet. They are supplied with blast by three vertical direct-acting blowing engines, made by Messrs. J. C. Stevenson and Co. of Preston. The steam cylinders are 33 ins. diameter, the blast cylinders 72 ins., and the stroke is 4½ ft. The general pressure of blast is 4½ lbs. to 5 lbs. per sq. inch, but a pressure of 6 lbs. can be got if required. In front of the engine-house is a range of nine Lancashire steel boilers by Messrs. W. and J. Galloway and Sons of Manchester. They are usually fired by the waste gases from the furnaces, sometimes supplemented by a little coal; or they can be fired entirely by coal. The blast is heated by seven of Cowper's regenerative hot-blast stoves, ranged in a line at the back of the furnaces. The tuyeres to each furnace are six in number, placed at equal distances around the hearth. Between the furnaces and the pig beds runs a line of rails, upon which the ladle for supplying the Bessemer converters is brought in, the tapping level being high enough to allow the metal to run down into the ladle while on its carriage.

The railway carries the metal across the river to the platform of the new Bessemer foundry, which is now being erected. The converters are two in number, and are each of 8 tons capacity. The bottoms are changed by means of a hydraulic ram, which is mounted on a truck that runs on rails from the tuyere shed to the converters; by this means an old bottom can be taken out and replaced by a new one within twenty minutes. At the back of the converters, and sunk through the platform, are the cupolas for spiegel and scrap, which have been thus placed low in order that the whole may be roofed in at some future time, if found necessary. The casting pit is 40 ft. diameter, and is served by three single-ram cranes. The casting crane is on Messrs. Tannett Walker and Co.'s three-ram plan for saving water, having two hydraulic pressure-rams and a central guide-ram. The blowing engines are vertical high-pressure compound condensing, with steam cylinders 42 ins. and 78 ins. diameter, and blast cylinders 55 ins. diameter, the stroke being 5 ft. In the same house are a pair of hydraulic pumping engines, which are fitted with

rams working behind the steam cylinders and connected to the piston-rods; the cylinders are each 18 ins. diameter by 2 ft. stroke. The blast for the cupolas is furnished by a three-cylinder engine. All these engines have been supplied by Messrs. Tannett Walker and Co. of Leeds. The condensing is effected by one of Bulkley's condensers, made by Messrs. Daniel Adamson and Co. of Dukinfield; with this condenser no air-pump is required, the vacuum being formed by condensation, and the water of condensation and injection-water being carried downwards through a vertical pipe and expelled against the atmospheric pressure by the momentum acquired.

In front of the casting pit will be placed four heating furnaces for taking the ingots hot from the moulds; each will be capable of taking nine ingots at once. The ingots will be charged and drawn by hydraulic apparatus common to all four furnaces; whence they will be taken to the 36-inch cogging rolls, driven by a pair of condensing geared engines by Messrs. W. and J. Galloway and Sons. The cylinders are each 40 ins. diameter by 5 ft. stroke, and the engine is geared 2 to 1. The ingot will be taken by carrying rollers from the cogging mill to the roughing rolls, which are 27 ins. diameter. Thence it will be pushed across to the finishing rolls, which stand in a line with the roughing train, by means of hydraulic apparatus. The cogging, roughing, and finishing rolls are all supplied by Messrs. Davy Brothers of Sheffield. The engines for working the rail mills are also by Messrs. W. and J. Galloway and Sons; they are not geared, and their cylinders are 50 ins. diameter by 4½ ft. stroke; they have also the Bulkley condenser. From the finishing rolls the rails are to be taken by carrying rollers to be cut to lengths by a circular swinging saw 5 ft. diameter, the required lengths being gauged by stops. The hot bank is 210 ft. long, and the rails are slid down along it by single and twin skids, which are worked by a pair of 6-inch horizontal engines at each end. The hot-bank machinery, as well as that of the rail yard, has been supplied by Messrs. Joshua Buckton and Co. of Leeds. The rail yard is roofed by five spans of galvanised iron, each 34 ft. wide and 118 ft. long, by Messrs. Morewood and Co. There are five double straightening presses, four rail-ending machines, and six

double drills, which are all driven by overhead shafting. Power is supplied by one of Messrs. Robey and Co.'s 40 horse-power semi-portable engines, having cylinders 14 ins. diameter by 22 ins. stroke. The rail benches are so placed that the finished rails are delivered straight into trucks on a lower level, so that no lifting is required.

Close to the blowing engines is a range of twelve Lancashire boilers by Messrs. Daniel Adamson and Co., for which the feed-water is heated by two of Green's economisers. The coal is brought in on a railway at a higher level, and shot into bunkers. A subway is provided in front of the boilers, along which runs a light railway used for removing the ashes. The chimney to these boilers is designed to serve two ranges of twelve, and is 202 ft. high.

The whole of this new and extensive plant has been designed by Mr. Edward Williams, of Middlesbrough, and has been carried out under the supervision of Mr. Edmund Hambly, the resident engineer.

In an older part of the works is the bar-rolling mill, in which there is a 10-inch train, and a guide-mill for smaller sizes, driven by an inverted oscillating engine with cylinder of 34 ins. diameter. There is now being erected a powerful lathe with overhead crane and gantry, for turning the heavy rolls of the steel-rail mill. Another old mill, known as the Castle mill, is undergoing alterations, and will be started again shortly. In the old puddling forge are eighteen puddling furnaces, with trains of puddling, roughing, and finishing rolls, and shears, squeezer, and tilt-hammer. Beyond is a 16-inch train of bar rolls, and roughing, planishing, and slitting rolls. The motive power is obtained from two water-wheels, each 20 ft. diameter and 37 horse-power. At a little distance is a large range of boilers, all past work, one of which is spherical and about 16 ft. diameter. Hard by is the first blowing engine erected at these works, and perhaps one of the earliest used anywhere, in appearance not unlike many now at work. Near it are a smithy still used; a foundry capable of turning out castings up to 25 tons in weight; and another puddling forge, containing seventeen furnaces, and a 16-inch puddle-train driven by a water-wheel of 36½ ft. diameter, 10 ft. width, and 58 horse-power.

RHYMNEY IRON WORKS.

The first furnace of these works was erected about eighty years ago near Rhymney Bridge, where they were carried on until they were removed to their present site, about twenty-four miles from Cardiff: the river Rhymney, which here forms the boundary between England and Wales, running through the middle of the premises. The works and the eight collieries belonging to them find employment for a staff consisting of about four thousand persons.

There are four pits and two drifts in the immediate neighbourhood of the works, three pits being on the Bute or Glamorgan side, and the two drifts and one pit on the Rhymney or Monmouthshire side. There are also two pits producing bituminous coal at distances of about $4\frac{1}{2}$ and 7 miles. All these collieries have underground haulages, the engines in all cases fixed on the surface. The two drifts and one of the collieries on the Glamorgan side are worked on the endless-rope system, while the five remaining pits have the tail-rope system. Where curves are numerous and gradients variable and steep, the tail rope is found most effective; whilst with long lengths of straight roads and easy gradients the endless rope gives excellent results. At the Darran pit, the farthest from the works, there is extensive underground pumping carried on. The pumps, which are a pair of Pearn's quadruple-acting fly-wheel pumps, with a capacity of 25,000 gallons per hour, are at the bottom of a drift about 1000 yards from the pit, and are driven by compressed air. The air-compressing engine is on the surface, and its air-cylinder is fitted with Walker's valves. The small coal from these collieries, used for coking purposes, is conveyed to washing machines in the immediate vicinity of the works. There are three of these machines, two on the plunger principle, and one on the open-trough plan. Two of them have rotary screens with travelling bands for cleaning the rubble, which is then crushed and usually mixed with the washed coal.

On the Monmouth side of the river are blocks of coke ovens on the hillside, on a level with the original charging platforms of the blast furnaces, but below the line of rails upon which the coal for

coking is delivered, so that the coal can be easily discharged from the wagons into the bunkers from which the ovens are supplied. The principal block consists of seventy-two Coppée ovens, along the top of which run three lines of rails for discharging the hopper trams into the openings in the top of the ovens. The ovens are emptied by a steam pusher. There is also a block of thirty-six ordinary ovens of recent construction, with fifty-one more of an older date. The waste gases from the Coppée and the block of thirty-six ovens are conveyed to a range of ten boilers, which supply steam to the furnace blowing-engines; four of the boilers are heated entirely from the coke ovens, four entirely by the furnace gases, and the two remaining boilers from the ovens and furnaces combined. In a second range of six boilers, heated by the furnace gases, provision is made for burning coal in the event of the gas being insufficient or the furnaces stopped or blown out.

The two blowing engines are of the usual beam type. The first is a condensing engine with steam cylinder 52½ ins. diameter, blowing cylinder 104 ins. diameter, and both 10 ft. stroke. The second engine is non-condensing, having a 50-inch steam cylinder, and 90-inch blowing cylinder, both with 12 ft. stroke; a second blowing cylinder of 72 ins. diameter with 6 ft. stroke has recently been added after the engine had worked some time, when a greater volume of blast was found necessary. The blast-pressure averages about 4 lbs. per sq. inch.

The blast furnaces on the Monmouthshire side of the river are three in number, rectangular in form of outer structure, close-topped, and of the old-fashioned solid masonry build so common in South Wales. Their original height, when used for producing forge-pig, was 42 ft.; but for the purpose of smelting Bessemer pig it has been necessary to raise them 13 ft. The materials are elevated to the new landing by two steam lifts, having inverted cylinders supported by iron columns, their piston-rods being attached direct to the cages. Eighteen cast-iron spiral stoves are placed beside the furnaces. In front of the furnaces is a subway, along which runs a railway for conveying the molten metal direct from the blast-furnaces to the Bessemer works close by. The railway passes four iron-melting

cupolas, which are blown by a couple of No. 7 Roots' blowers, and are used for melting the iron made at any time when the Bessemer works may be stopped, and also for working up scrap in conjunction with pig iron.

In the Bessemer department are two pits, the first having three converters, two of which are placed side by side, and the third very nearly at right angles to them. The metal is brought in an ordinary foundry tipping-ladle on a carriage from the furnaces, on the level of the converter-house floor. The ladle is lifted for tipping into the converters by a hydraulic charging crane, which also charges the spiegel, and after the blow transfers the metal to the casting crane. This arrangement has proved very successful in the manufacture of steel for tin-plate bars, as by tipping the product into a second ladle after being received from the converter a very thorough mixture of the ferro-manganese is obtained. Three ingot-cranes are arranged around the casting-pit. The second pit has two converters placed side by side, and the metal is brought in a ladle tipping on its carriage upon a platform in front of and on a level with the converters when in position to be charged. The spiegel is charged in the same way from a small ladle running on a narrow-gauge railway. The charging crane is thus dispensed with. A casting crane, two ingot-cranes, and a ladle-crane, complete the equipment of this pit. All the ingot-cranes, the casting-cranes, and the charging-crane at these works have Walker's balanced rams, by which a most important saving is made of water under pressure, as may be noticed when comparing the limited extent of pumping power at these works with the number of hydraulic machines worked. The converter-house, machinery, vessels, cranes, ladles, cupolas, &c., were made by Messrs. Tannett Walker and Co. The largest make of Bessemer steel in one week at these works has been 3170 tons.

The pair of converter blowing-engines, by Messrs. Galloway, are vertical direct-acting, with steam cylinders 45 ins. diameter, blowing cylinders 54 ins., and 5 ft. stroke, the flywheel being driven by a return connecting-rod. The maximum blast-pressure is 25 lbs. per sq. inch. A pair of auxiliary blowing engines of the same kind, and by the same makers, have steam cylinders 30 ins.

diameter, air cylinders 40 ins., and 4 ft. stroke, delivering into the same blast-main as the larger engines. Both pairs of engines are non-condensing. Between them are two pairs of horizontal hydraulic engines, also by Messrs. Galloway, with steam cylinders 16 ins. diameter, plungers 4½ and 6 ins. diameter, and stroke of 15 ins.; one half only of the suction is discharged from the pumps into the hydraulic main at each stroke, thus equalising the work on the engines. The working hydraulic pressure is 600 lbs. per sq. inch. The accumulator ram is 24 ins. diameter, with 14 ft. stroke. These hydraulic and blowing engines are supplied with steam from a range of ten boilers, six of which are by Messrs. Daniel Adamson and Co., and four by Messrs. Galloway. Bottom stoves and ganister sheds complete the Bessemer plant.

The principal rolling mill is situated at a little distance below the Bessemer works. The cogging mill has a pair of rolls 30 ins. diameter, and is driven direct by an inverted-cylinder engine, with cylinder 50 ins. diameter by 4 ft. stroke, and a flywheel of 72 tons weight and 28 ft. diameter, the ring being all cast in one piece. This engine as well as the whole of the mill was originally laid down for plate-rolling about twenty years ago; and the present modern machinery for steel-rail rolling was erected after the completion of the Bessemer plant. This mill is reversed by the three mitre-wheel reversing gear originally used, which has been retained, the clutches being moved by steam power. From the cogging mill the blooms are conveyed upon live rollers to a powerful guillotine shears, where they are cut to the required length. They are then reheated, and roughed down in a 26-inch roughing mill, driven by a pair of 60-inch cylinder non-condensing engines of 4 ft. stroke. Originally this was a single engine and a duplicate of the 50-inch now driving the cogging rolls, but without the reversing gear. To adapt it to its present use the flywheel was removed, and the vertical 50-inch cylinder was replaced by a 60-inch; and to convert it into a reversing engine a horizontal cylinder was added, with its connecting-rod working on the same crank-pin as the vertical; a single-bow crank thus serves for both cylinders. This arrangement could not be very well carried out without adopting

Joy's valve-gear to simplify the construction; and the whole has been found to work very satisfactorily. The cylinders, connecting-rods, and all other new parts were made by Messrs. Tannett Walker and Co.

From the roughing mill the bar is carried by mechanism to the 24-inch finishing mill, which is driven by a pair of horizontal engines of foreign make, with 40-inch cylinders and 4 ft. stroke. The pinions have helical teeth. This engine works with 80 lbs. steam pressure, while the others work at 40 to 45 lbs. The roughing engine and the finishing engine are so arranged that either of them can drive both mills if necessary, in case of breakdown or any cause requiring the stoppage of one or other. From the finishing mill the bars are conveyed on live rollers to the saws, where they are cut into three, four, or five lengths, as may be required. From the saws they are carried by mechanical appliances along a hot-bank about 200 ft. long to the presses. The machinery for the rail-carrying appliances, and also the main length of live rollers, were made by Messrs. Joshua Buckton and Co. After straightening, the rails are conveyed by another skid to the measuring benches, where they are sorted and forwarded to the rail-ending machines, of which there are two double and two single, by Messrs. Buckton, or to the drilling machines as may be required; of these latter, part were made by Messrs. Craven, and the remainder by Messrs. Buckton. At night the mill is illuminated, where necessary, by the Brush electric light. Over 1800 tons of light rails have been made in this mill in one week.

On the Glamorganshire or Bute side of the river are six furnaces, two only being now in blast; these are interesting examples of old appliances skilfully turned to modern uses. Built in 1835, in the old solid masonry style, they have had their original height of 45 ft. raised to 60 ft.; at the same time the bottom arrangements have been altered so as to enable a higher temperature of blast to be used than could be obtained from the old cast-iron stoves. Each furnace has six tuyeres. Four Whitwell stoves of 65 ft. height and 22 ft. diameter heat the blast for the two furnaces. There are three blowing engines, one of which has a 56-inch steam cylinder and 120-inch blowing cylinder, with 8 ft. stroke; and

another has a 60-inch steam cylinder and 120-inch blowing cylinder, with 8 ft. stroke; these two engines are usually coupled, but at present one only is worked. In an adjoining house works the third engine, with a 38-inch steam cylinder, 100-inch blowing cylinder, and 8 ft. stroke, which discharges its blast into the same main as the others. The blast pressure is $4\frac{1}{2}$ lbs. per sq. inch. At the back of these furnaces is a block of eighty-six Coppée coke ovens, whose waste gases are used under the boilers supplying steam to the blowing engines. Several other blocks of coke ovens of the usual construction lie in the immediate neighbourhood of the furnace tops. Near the furnaces is an old rail-mill, now used for light steel-rails and fish-plates; it comprises a small compact 30-inch blooming mill driven by a pair of 25-inch reversing engines, geared to mill shaft, with live rollers complete; all made on the premises. A powerful guillotine by Messrs. Buckton cuts the blooms to lengths. The rolling mills are driven by a 48-inch cylinder beam-engine with 8 ft. stroke, geared to the mill shaft. Saws, presses, punching, straightening, and grinding machines for fish-plates and rails lie close at hand. On the Glamorgan side also are the machine shops, forge, pattern shop, erecting shop, foundry and railway wagon yard; and about three quarters of a mile up the valley are extensive brickworks with hydraulic machines for making tuyeres, runner-bricks &c., for the Bessemer works, and also grinding mills and stone-breaker for the manufacture of ganister for the same uses, all the grey and black ganister being made at the works.

EBBW VALE IRON WORKS.

These works, commenced more than a century ago by Jeremiah Homfray, who came into South Wales from Staffordshire, have been augmented by successive additions, until their original site has now been extended to 5,000 acres; and the total area of properties owned by the company, including those at Abersychan, Pontypool, and Abercarn, amounts to 10,930 acres. In 1883 the total output from the four collieries at Ebbw Vale and those at Abersychan and Pontypool was 1,486,000 tons; the coke made was over 273,000 tons, the coking plant being equal to a production of 340,000 tons

per annum; and nearly 6,000,000 bricks were made. The year's production of pig iron and spiegel-eisen was 212,412 tons; the finished iron and steel reached 131,780 tons, including 11,120 tons of iron bars, angles, and fish-plates made at Ebbw Vale, 116,572 tons of steel rails, bars, and fish-plates also made there, and 4,088 tons of coke-bars and sheets made at Pontypool. The castings made were 10,997 tons at Ebbw Vale, and 581 tons at Pontypool.

The Ebbw Vale Works extend from north to south along the banks of the River Ebbw. At the northern or upper end are the four Ebbw Vale blast-furnaces, and at the southern or lower end the more recently erected Victoria furnaces.

The four Ebbw Vale furnaces are of modern build, and all are 60 ft. high, hooped with iron bands. Nos. 1 and 2 are 16 ft. diameter at the boshes, 7½ ft. across the hearth, and 10 ft. at the throat; Nos. 3 and 4 are 18 ins. larger across the boshes. There are four tuyeres in each except No. 3, which has five tuyeres equally spaced, and a dry-rammed ganister hearth, said to give good results. Of the three blowing engines for these furnaces, two erected about five years ago by the Coalbrookdale Iron Company are condensing beam-engines, having steam cylinders 45 ins. diameter, blowing cylinders 90 ins., and 6 ft. stroke. The pressure of blast is 4 lbs. per square inch. The steam cylinders are jacketed with the exhaust steam, which is discharged into a double casing surrounding them. The valves are double-beat, and are worked by roller gear; there is also an expansion-valve giving a cut-off at about half-stroke. Steam is supplied by a range of fourteen Cornish boilers 35 ft. long and 7 ft. diameter, with flue 3½ ft. diameter. They are all fired with the waste gases from the furnaces, but can if necessary be fired with coal. The third blowing engine is also a beam engine, with steam cylinder 72 ins. diameter, blowing cylinder 144 ins., and 12 ft. stroke. The flywheel is 30 ft. diameter, weighs 90 tons, and makes 12 revolutions per minute. This engine was started about eighteen years ago, and on the second day of running the cast-iron crank broke; one of wrought iron was then substituted, and the engine ran very well until about five years ago, when the crank-shaft broke short off in the journal at the crank end. A crank-shaft and

crank-pin of Whitworth fluid-compressed steel were then fitted, which are at present in use in conjunction with the former wrought-iron crank. The diameter of the crank-shaft in the bearings at the crank-end is 20 ins., and the length 3 ft., the total length being 15 ft. 2 ins.; the shaft is square where the flywheel is blocked on. The air valves are horizontal, with balance weights, and the blast is delivered into the same main as from the two other engines. Steam is supplied from a range of four Cornish boilers, 40 ft. long and 7 ft. diameter, with a 4-ft. flue and six Galloway tubes in each. They are all gas-fired, no provision being made for coal. Near them, and convenient to the railway along which the Bessemer ladle is brought from the furnaces, are two cupolas, used for assisting the furnaces when enough iron is not got from them, and for working up pig made on Saturdays or Sundays. At the back of the furnaces are five Cowper stoves, 24 ft. diameter and 47 ft. high, all connected with one hot-blast main. These stoves supply only Nos. 1 and 2 furnaces, the other two furnaces being served by fifteen ordinary cast-iron pipe-stoves.

On a higher level at the rear of the furnaces are stored the ore and limestone, which with the coke are raised 16 ft. to the charging platform by means of four direct-acting steam-lifts with cylinders underneath. Still higher on the hillside are two blocks of 33 and 34 coke ovens, from which it is intended to collect the waste gases for heating the boilers. On the lower ground is the truck-repairing and general carpenter's shop, where the 3,500 trucks belonging to the works are kept in proper order, and other wood-working is carried on; also the locomotive repairing shed for the 32 locomotives, and smithy and fitting shop with all necessary tools, and travelling steam jib-cranes for shifting the work.

The Bessemer steel works are situated about halfway down the railway from the Ebbw Vale to the Victoria furnaces. Here is the roll-turning shop containing eight lathes, each of which will take rolls up to 12 tons weight and 9 ft. length; overhead is a steam travelling crane which will lift 20 tons. In the steel works are three pits, each with two converters placed opposite to each other. The most modern pit is $17\frac{1}{2}$ ft. radius, and has a pair of 10-ton

converters lined with silica bricks. Each is blown by nineteen tuyeres, which are pierced with eight ½-inch holes, in place of the sixteen smaller holes used formerly, the larger holes being found to answer better. The two other pits are of the old deep kind, and have each two 8-ton converters. Of the two pairs of blowing engines, one by Messrs. Daniel Adamson and Co. is vertical direct-acting, having 40-inch steam cylinders with 54-inch blast cylinders and 5 ft. stroke. The pressure of blast is 25 lbs. per square inch. A Bulkley condenser is attached, and is used when water is very plentiful. The other pair of engines, by Messrs. W. and J. Galloway and Sons, are horizontal, having 36-inch steam cylinders, 48-inch blast cylinders, and 5 ft. stroke. They are non-condensing, the exhaust steam being taken to heat the feed-water. Both these pairs of engines deliver into the same blast-main, and take steam from the same boilers. Close by are three pairs of horizontal hydraulic pumping engines by Sir W. G. Armstrong and Co., for working the Bessemer plant and the rail mills; their steam cylinders are 18 ins. diameter, rams 4½ ins., stroke 2 ft., and water-pressure 450 lbs. per square inch.

In the rolling mills is a pair of horizontal blooming engines by Messrs. W. and J. Galloway and Sons, geared 3 to 1; the cylinders are 36 ins. diameter with 4½ ft. stroke. One of Messrs. Hathorn Davey and Co.'s separate condensers is used, with a differential pump. The engines drive two trains of 36-inch rolls, one on each side. The rolling-mill train, 30-inch centres, is driven by a pair of vertical engines geared 1½ to 1, cylinders 50 ins. diameter and 4 ft. stroke. The heating furnaces, eight in number and fired with gas, are of considerable depth, and are charged on each side; hydraulic gear is used for pulling out. The gas producers are in six blocks of four fires each. The boilers supplying the steel works are thirty in number, all fired with coal. Fifteen made by Messrs. Daniel Adamson and Co. are 30 ft. long and 7 ft. diameter, containing one flue of 3 ft. 10 ins. diameter and two cross tubes. Six are Galloway boilers of the same length and diameter. Nine are by the Coalbrookdale Company, and are 34 ft. long and 7 ft. diameter, having two flues 2½ ft. diameter; these nine are fired underneath, the others being internally fired.

To provide against drought, the water which has been used for boilers, condensers, water-tuyeres, and coal-washing machinery, is returned through a height of about 225 ft. and a distance of about three quarters of a mile to a small reservoir above the Ebbw Vale furnaces. Two pumping engines are employed for this purpose: one is a Cornish engine with 60-inch steam cylinder, 17-inch plunger, and $6\frac{1}{2}$ ft. stroke; the other has a 40-inch steam cylinder with 4 ft. stroke, and is geared 4 to 1 to the crank-shaft, which works two pumps with 12-inch barrels and 6 ft. stroke.

The Victoria blast-furnaces are two of 60 ft. height, 20 ft. diameter at boshes, 8 ft. at hearth, and $13\frac{3}{4}$ ft. at top. One has a fire-brick hearth, and the other is rammed with dry ganister; both are hooped with iron, and have seven tuyeres. Two more furnaces are about to be built. The two blowing engines, by Messrs. Kitson and Co., have vertical steam cylinders of 50 ins. diameter, over air cylinders of 100 ins. diameter, the stroke being 5 ft.; they have piston steam-valves and circular blast-valves. The blast-pressure is 5 lbs. per sq. inch. The foundations are already laid for two more engines of the same kind. For heating the blast there are six Cowper stoves, 20 ft. diameter and 60 ft. high, ranged behind the furnaces. In the erection of these regenerative stoves the dome of the stove was first riveted together on the brick base, and was then lifted high enough for riveting to it the uppermost circle of shell-plates of $\frac{3}{8}$ inch thickness. This portion was next lifted high enough for another circular tier of plates; and so on, until the full height of the stove was attained. The lifting was done by means of a wood derrick, with a couple of geared crab-winches worked by hand; and when the shell was built up to half the full height, two more crab-winches were added for completing it. The brick lining was afterwards built in from the bottom upwards by means of a movable platform inside, with a trap-door in it through which the materials were hoisted in a tub by a small steam-winch. The platform itself was also lifted by the winch in successive stages, as the lining rose; and rested on the top of the lining during the intervals while the winch was winding materials. The regenerative brickwork and flame-flue were built in after the lining was completed.

Adjoining is a range of ten steel boilers by Messrs. Daniel Adamson and Co., 30 ft. long and 7 ft. diameter, with 3-ft. flues and six cross tubes; all are fired with gas, and fed by a Cameron pump. Two Berryman feed-water heaters take the exhaust steam from the engines. Two of Messrs. Hathorn Davey and Co.'s horizontal pumps with differential gear return the tuyere water to a reservoir. All the materials for these blast-furnaces are stored at the tapping level, being lifted on steam hoists with wire rope by a pair of winding engines with 12-inch cylinders and 20 ins. stroke, geared 5 to 1.

In the foundry are made rolls and all necessary castings up to 30 tons. On higher ground are seven blocks of coke ovens, six of them on the Coppée principle; their waste gases heat nine boilers, which supply steam for two coal-washing machines on the plunger plan, and also for the engines at the mouths of two pits close by, and for a pumping engine which returns the coal-washing water to a tank on the top of the machine. There are three steam pushers-out for discharging the Coppée ovens.

The bar mill contains a 12-inch train, driven by an engine with cylinders 24 ins. diameter by 30 ins. stroke, making 70 revolutions per minute; and an 8-inch guide-mill, having an engine with 21-inch cylinders by 20 ins. stroke, making 112 revolutions per minute. Both trains are driven by cotton rope from the fly-wheel pulleys of 14 ft. diameter and 2 ft. width, which have eight grooves; the driven pulley on the 12-inch train is $7\frac{1}{2}$ ft. diameter, whilst that on the 8-inch train is $6\frac{1}{2}$ ft. The distance between the centres of the pulleys is 30 ft., and ropes $1\frac{3}{4}$ inch diameter are used. An 18-inch train for rolling fish-bars and large iron and steel bars up to $3\frac{1}{2}$ ins. or 4 ins. is driven by a pair of horizontal engines with 30-inch cylinders and $4\frac{1}{2}$ ft. stroke, geared 3 to 1. Seven boilers fired by the waste heat from the heating furnaces are each 24 ft. long by 7 ft. diameter, having two flues of $2\frac{1}{2}$ ft. diameter, one furnace delivering into each flue.

In the steel-rolling mills a new 36-inch blooming mill is now being erected, with a pair of engines by Messrs. Galloway and Son, having cylinders 36 ins. diameter by $4\frac{1}{2}$ ft. stroke, geared 3 to 1. This mill has helical pinions, and the top rollers are balanced with

hydraulic cylinders; hydraulic power is supplied for passing the bloom, and also for turning over. The adjoining mill-train is worked by an old beam-engine with a horizontal engine coupled to it, geared $2\frac{1}{2}$ to 1. There are twelve boilers, 24 ft. long by 7 ft. diameter, with two flues $2\frac{1}{2}$ ft. diameter, which are heated by waste gases from the heating furnaces, one furnace delivering into each flue; there are also fifteen similar boilers fired with coal.

ABERCARN TIN-PLATE WORKS.

These extensive tin-plate works are in two portions, old and new, connected with the railway and with each other by sidings. The old portion contains the usual machinery for the rolling and re-rolling and shearing of the iron plates; with the appliances for pickling, cleaning, and dipping them, first in boiling palm oil and afterwards in the baths of molten tin. Adjoining are the sulphuric acid works. The new portion of the works, at a distance of a quarter of a mile, contains the same machinery and appliances, but of more modern make, with packing shop and extensive warehouse for storing the boxes of tin-plates.

WORKS IN NEWPORT

OPENED TO THE VISIT OF THE MEMBERS.

Alexandra Dock.
Cambrian Foundry and Engineering Works.
Mordey Carney and Co.'s Shipbuilding Works and Dry Docks.
Emlyn Foundry and Machinery Stores.

ALEXANDRA DOCK.

The dock was opened in April 1875, Mr. James Abernethy and Mr. Alexander Bassett being the engineers. The present engineer is Mr. William Stopford Smyth. The dock is 2500 ft. long, 500 ft. wide, and has an area of $28\frac{3}{4}$ acres. The entrance lock, on the right bank of the River Usk, is 350 ft. long and 65 ft. wide, with 36 ft. of water on the outer sill at average spring tides and $25\frac{3}{4}$ ft. at average neap tides. There are three pairs of timber

working-gates, and one pair of iron sea-gates, all worked by hydraulic power. The inner sill is 8 ft. above the outer sill, and the ordinary level of water in the dock is 30 ft. above the dock sill. There are three Siemens electric lights at the entrance, each 34 ft. high and of 6000 candle-power, worked by two 8-H.P. Otto gas-engines. Vessels are thus enabled to enter the dock as freely by night as by day.

The dry dock is entered from the wet dock. The length is 515 ft. on the blocks, and the width 74 ft. between the copings. The gates are 50 ft. wide, with 20 ft. of water on the sill. The dock is emptied by a culvert discharging into the river. Alongside the dry dock are the fitting and repairing shops, and the foundry, with the necessary machinery for all kinds of repairs to vessels and engines.

A timber float of 10 acres area and 8 ft. depth is connected with the wet dock by a canal; and there are in addition about 160 acres of land for general purposes, and 93 acres for depositing ballast.

The railways and sidings immediately in connection with the dock are 27 miles in length. The coal sidings are laid out on the gravitation principle, so that the loaded wagons run down from the high-level sidings to the quay, where they are weighed, and are then taken by the hydraulic capstans to the hydraulic hoists, raised to the required height, tipped by hydraulic power, and transferred to railway viaducts which cross the quay and lead them by gravitation to the sidings for empties. The lines for loaded wagons from the high-level sidings to the quay are laid in sets of twos and threes, to allow wagons with different kinds of coal to be tipped in rotation, thus ensuring the due mixture of coal, as may be required. Wood's safety railway-chair is in use on the dock lines.

There are eight hydraulic coal-hoists with their accompanying sorting sidings, weigh-bridges, viaducts, and sidings for empties. Vessels are discharged by hydraulic cranes of from two to three tons power. Of these there are seven movable and six fixed. There are also five steam-cranes of from two to ten tons power.

The hydraulic power for the gates, hoists, capstans, and cranes, is furnished by three steam pumping-engines of 220 H.P. collectively,

with seven boilers and three accumulators. Two of the accumulators are 17 ins. diameter and 17 ft. lift; the third is 20 ins. diameter and $23\frac{1}{2}$ ft. lift. The traffic is worked by thirteen locomotives. A powerful steam hopper-barge, fitted with Priestman's crane and bucket, removes the silt in the dock and acts as a tug-boat.

For the extension, or South Dock, 213 acres of land have been acquired, with 100 acres adjoining for ballast purposes.

From 700 to 800 men are engaged about the dock, including the officials and the men loading and discharging the vessels.

The principal exports are coal and steel; the imports are iron-ore, pig-iron, timber, pitwood, and sleepers. The coal shipped in 1876 was somewhat less that half a million tons; in 1883 it exceeded $1\frac{3}{4}$ million tons; while the total exports and imports in 1883 amounted to nearly 2,400,000 tons. The number of vessels that entered the dock in 1883 was 1848, of nearly 1,100,000 net register tonnage.

CAMBRIAN FOUNDRY AND ENGINEERING WORKS.

These works were established in 1849, and are now employing 300 hands, and are capable of turning out 400 tons of castings per week. They are situated on the right bank of the River Usk, adjoining the Newport Docks, and have a river frontage of nearly a quarter of a mile. On the opposite side of the river are other works, where the founder of the firm (the late Mr. Thomas Spittle) commenced iron-shipbuilding a few years ago; but this branch of the business was discontinued after the construction of two ships, and the shipyard has since been utilised for the building of locomotives and for ordinary engineering work.

MORDEY CARNEY AND CO.'S SHIPBUILDING WORKS AND DRY DOCKS.

These works, covering about five acres, were leased from the Newport Dry Dock Co. in 1881 by the present proprietors, who have since made considerable additions to them. They consist of the Alice dock, 300 ft. long and $46\frac{1}{2}$ ft. wide, and the Edith dock,

220 ft. long and 36 ft. wide, with extensive smiths', joiners', and blockmakers' shops, sawmills, shipbuilding sheds, &c., well supplied with all the machinery necessary for the construction of wood and iron ships, marine engines, &c. About 200 men are at present employed. A pair of surface-condensing engines of 40 H.P., specially designed for small steamers, were in course of construction, and nearly completed at the time of the Members' visit to Newport.

SEVERN TUNNEL WORKS.

The Act for the construction of the tunnel was obtained in 1872, between which date and October 1879 the Great Western Railway Co. sank five shafts and drove about three miles of headings to prove the nature of the ground. The headings under the river were within 130 yards of meeting, when the works were drowned out by the sudden breaking in of a large land spring on the Welsh side, which completely filled them. The contract was then taken by Mr. Thomas A. Walker, who erected extra pumps, and by December 1880 succeeded in draining the works; and from that time to the present the permanent work of the tunnel has progressed steadily, with the exception of a few hindrances incidental to an undertaking of this magnitude.

The total length of the tunnel when completed will be 7664 yards or about $4\frac{1}{3}$ miles, of which about $2\frac{1}{4}$ miles' length is under the actual tidal estuary of the Severn, crossing it about 3 miles below the confluence of the Wye. About 5500 yards of the tunnel are wholly completed, and 1860 yards are about half done. The whole length of the tunnel has already been opened through from end to end, excepting only a short length in the land portion on the Monmouthshire shore, where in October 1879 the land spring was struck, discharging some 6,000 gallons per minute. In October 1883 the same spring was again tapped at a lower level, giving on this occasion 20,000 gallons per minute; after three weeks'

continuous pumping the water in the shaft was lowered sufficiently to show that after the first rush the pumping power was equal to the inflow. Two dams of heavy brickwork have here been constructed across the tunnel, about 100 ft. apart, for shutting off the spring from the remainder of the workings; and have been fitted with sluices for regulating the inflow to the pumps. A curved heading is now being driven round one end of the dams, for connecting the two portions of the tunnel; and as soon as it taps the spring, the inflow here occurring will be overpowered by the pumps, so as to allow of removing the dams and completing this short gap of the tunnel. Hitherto the quantity of water raised at the Sudbrook pumping station adjoining the dams, by three Cornish and two Bull engines, has been about 11,000 gallons per minute; and the addition of four more large Cornish engines, made by Messrs. Harvey of Hayle, will bring up the aggregate pumping capacity at this station to about double that quantity; the pumping power will then be sufficient to deal quickly with the greatest flow of the spring. The total capacity of the nineteen pumping engines employed on the tunnel works is over 30,000 gallons per minute.

The tunnel is for a double line of way, and is lined with brickwork varying from $2\frac{1}{4}$ ft. to 3 ft. in thickness, built of vitrified bricks which are set in Portland cement mortar. The roof is a semicircle of 13 ft. radius inside, and the side walls are curved, with invert at bottom; when filled in up to formation level for the rails the open area will be 441 square feet. The tunnel dips from both shores to a point beneath the deepest part of the river bed; and underneath the Monmouthshire half are two driftways, one a 5 ft. barrel lined with brickwork, for drainage to the pumping station at Sudbrook, and the other a 9-ft. barrel for ventilation. The whole of the workings are most efficiently ventilated by a Guibal fan at the same station, 18 ft. diameter and 7 ft. wide, driven by a 10-H.P. engine. Electric lights of 1000 candle-power are suspended about every 220 yards along the tunnel, and are used also above ground. The cutting forming the approach to the tunnel at the Monmouthshire end is about a mile long, and 60 ft. deep at the tunnel mouth; about two-thirds of it are

completed. At the Gloucestershire end there is about a mile and a quarter of cutting, 60 ft. deep at the tunnel mouth; four steam navvies are at work here night and day, and more than half the material has already been removed. As both these cuttings lie in the marsh lands adjoining the Severn, heavy sea-banks have been tipped to prevent high spring tides from entering the tunnel.

It is estimated that the whole of the works will be completed within twelve months hence. Sir John Hawkshaw is chief engineer, and with him is associated Mr. Charles Richardson of Bristol, who first laid out the line of the tunnel and prepared the parliamentary plans. The works are being carried out under the superintendence of Mr. A. G. Luke as resident engineer for Sir John Hawkshaw.

MEMOIRS.

John Borrie was born at Dundee on 27th November 1837. His father, Peter Borrie, who had been proprietor of the Dundee Foundry, went to Middlesbrough in 1853, and established himself as a shipbuilder. In 1856 John Borrie was first employed in the engineering office of Messrs. Bolckow and Vaughan at Middlesbrough, where he remained until 1861. In that year his health failed, symptoms of lung-disease appearing. He made a voyage to the Mediterranean, and returned much benefited; and afterwards became associated with Messrs. Sproat Brothers, ironfounders and engineers, Middlesbrough, with whom he remained until the partnership was dissolved in 1864. In 1866 he became resident engineer at the Cleveland Iron Works, Eston. This position he filled with much efficiency, during extensive alterations by which the plant was practically reconstructed. The new blast-furnaces at that time erected were the largest in capacity and height in the kingdom. He designed and set to work the hopper-and-spout kilns for calcining ironstone, which have since become general, reducing the cost for labour very considerably; an illustrated description of these kilns was given in "Engineering" of 26th November 1869. In consequence of impaired health he was compelled during the winter of 1870–71 to resign this post; and he subsequently practised as a consulting engineer. He had great mechanical ability, and was a good designer of machinery and appliances, notably those connected with the manufacture of iron. He died of heart disease and congestion of the lungs, at Stockton-on-Tees, on 8th February 1884, in his forty-seventh year. He became a Member of the Institution in 1869.

William Bragge was born at Birmingham on 31st May 1823, his father being a manufacturing jeweller. At the age of fourteen he entered the office of Mr. C. H. Capper, civil engineer, of

Birmingham, who was then engaged in the construction of the Kilsby Tunnel near Rugby, on the London and Birmingham Railway, after the failure of the original contractor. Subsequently he was at the Vulcan Works and Foundry of Mr. William Middleton, Birmingham; and at the age of twenty-one entered the service of the Birmingham and Gloucester Railway at Bromsgrove. Soon afterwards he was engaged by Messrs. Gandell and Brunton, railway engineers, Birkenhead; and then by Mr. Lister, whom he shortly succeeded as engineer of the Chester and Birkenhead Railway; he also planned and laid out the railways about the Birkenhead docks. In 1846 he went to Brazil as superintending engineer for the construction of the gas works at Rio de Janeiro. He also constructed the first railway in Brazil, the steep mountain line from Rio de Janeiro to Petropolis; and gas, railway, and harbour works at Buenos Aires. Returning to England in 1858 he joined the firm of Messrs. John Brown and Co., Atlas Steel Works, Sheffield, where the rolling of iron armour-plates and the manufacture of steel rails was shortly afterwards commenced. During the fourteen years of his connection with Sheffield he took an active part in promoting the education and welfare of the artisans; and his efforts resulted in the establishment and successful development of numerous important institutions for the benefit of the town. After 1872 he was for some time in Paris, as engineer to a scheme for utilising the sewage of the city. In 1876 he returned to Birmingham, and became interested in the manufacture of watches by machinery, on the American system, which he greatly improved in mechanical detail. For several years his sight had been failing, and he had become almost totally blind some time before his death, which took place at Birmingham on 6th June 1884, in the sixty-second year of his age. He became a Member of the Institution in 1854; and on the occasion of the Summer Meeting being held in Sheffield in 1861 he took an active part in connection with the remarkable paper then read on the manufacture of steel rails and armour-plates. At the Autumn Meeting of the Institution in Birmingham in 1883 the factory of the English Watch Company was visited on his invitation.

Massey Bromley, son of the Rev. T. Bromley, vicar of St. Mary's, Leamington, was born at Wolverhampton in 1846, educated at Leamington College, and afterwards at Brasenose College, Oxford, where he graduated M.A. in 1872. In February 1869 he went to Stratford, London, as pupil to Mr. Samuel W. Johnson in the locomotive works of the Great Eastern Railway, and passed through the shops, running shed, and drawing office; and during 1872–73 was sent as inspector of the building of locomotives for that railway at the Avonside Engine Works, Bristol. In 1873 he was appointed running-shed foreman for a time. From 1874 to 1878 he was works-manager under Mr. William Adams; and in 1878 succeeded Mr. Adams as locomotive superintendent, which position he held until 1881, when he resigned. In June 1882 he joined Mr. John C. Wilson in business in Westminster, and was with him until his death, which took place on 16th July 1884, at the age of thirty-seven, when he was one of the passengers killed in the railway accident at Penistone. In 1873 he devised some improvements in lathes for facing and turning tyres, &c. He became a Member of the Institution in 1877.

Charles Edward Darby was born at Coalbrookdale, Shropshire, in March 1822, and died at Brymbo near Wrexham on 28th May 1884, at the age of sixty-two. He went to Brymbo in 1846, and for about thirty-five years from that date was managing partner of the Brymbo Iron Works. His chief researches were in the way of utilising the waste gas from blast-furnaces; and his mode of taking off the gas was considerably adopted at the time (see Proceedings 1860, page 254). He was also largely interested in various collieries and lime-works in the district. He became a Member of the Institution in 1864.

Richard Garrett was born at Leiston in the county of Suffolk on 22nd July 1829, and received his education at a private school at Wickham Market. At the age of fourteen he was apprenticed to his father, the then proprietor of Leiston Works, which was established in the year 1778 as an iron foundry, sickle and general "agricultural implement manufactory," by the Richard Garrett of that day, who

was the great-grandfather of the subject of this memoir, and who had been previously engaged in a business of a similar character at Woodbridge. In 1850 Mr. Garrett assumed the responsibility of works manager in this rapidly increasing business, and in 1853 he became a partner in Leiston Works, devoting his energies especially to the development of the thrashing machine, first as a horse implement, and afterwards as a steam machine combining the operations of thrashing, dressing, and straw-shaking. On the portable steam engine he also bestowed great attention, arriving at very decided conclusions with respect to various controverted points: he regarded the steam-jacket as misapplied to commercial portable engines with low expansion, short stroke, and high speed of piston; while for double-cylinder portable engines of a higher class he strongly advocated the compound system of expansion regulated by governors operating directly upon the initial pressure of the steam, in preference to the more popular system of a high rate of independent expansion with a corresponding range of temperature in each cylinder, such independent expansion being in many cases effected by two pairs of slide-valves having their cut-off regulated automatically by the governors. His health having been failing for some years, his death took place from heart disease, on 30th July 1884, at the age of fifty-five. He became a Member of the Institution in 1882.

John J. Geach was born at Ashburton, Devonshire, on 21st October 1840; and died at Weston, Bath, on 24th December 1883, aged forty-three. In 1854 he was articled for three years to Mr. John Wright, in the locomotive works of the South Devon Railway, Newton Abbot. Afterwards he had charge of the erection of several bridges, one in Bristol; and was also employed on the Bristol harbour railway. In 1871 he was engaged on the works of the Severn Tunnel near Portskewett, and remained there until 1880. The rock-drills and other machinery used at the tunnel were from his own designs, and a description of them was given in his paper at the Bristol meeting of the Institution in 1877 (see Proceedings 1877, page 206). He became a Member of the Institution in 1878.

William Arthur Harrison was born in Manchester, and served his time there with the late firm of Messrs. Lewis and Sons. He then went to the Crewe Works; and afterwards returning to Manchester was with the firms of Messrs. E. T. Bellhouse and Co. and Messrs. Peel Williams and Peel, until he joined Mr. James Allen, thus forming the firm of Messrs. Allen Harrison and Co., Cambridge Street Works, Manchester. Of this firm he was a member for twenty-seven years, up to the time of his death, which occurred at his residence, Oakfield, Hale, Cheshire, on 23rd February 1884, at the age of fifty-four. He became a Member of the Institution in 1865.

John Lancaster was born at Radcliffe, near Bury, Lancashire, on 19th September 1815, and from a very early age showed a strong liking for mechanical and mining engineering. When about twenty years old, he joined one of his brothers in boring for coal on Chat Moss; and in 1841 he projected and carried on the sinking of the shaft for the colliery at Patricroft, through the permian formation, reaching coal at a depth of 440 yards. Whilst engaged in the practical management of this colliery, he started about 1844 the lower cannel pits subsequently belonging to the Ince Hall Coal and Cannel Co. In 1845 he started the Kirkless Hall Colliery, Aspull, near Wigan. From 1847 he acted for several years as mineral agent to Lord Mostyn, at Mostyn Colliery. From 1849 to 1856 he had the management of Earl Granville's ironworks and collieries at Shelton, North Staffordshire, and erected the Shelton Bar Iron Works. In 1855 he took charge of sinking the Shireoaks Colliery near Worksop, 520 yards deep, which was completed in 1858. From 1856 to 1860 he built five blast-furnaces at the Kirkless Hall Iron Works, which were the first iron-smelting furnaces in Lancashire, excepting two small charcoal furnaces at Ulverston. From 1865 to 1870 he was chairman of the Wigan Coal and Iron Co., comprising the Kirkless Hall and other works. Subsequently he was for the rest of his life chairman of the West Cumberland Iron and Steel Works. Other works with which he was concerned were the Bestwood Coal and Iron Works, near Nottingham; the Eldon

Colliery, Durham; and the Nantyglo and Blaina Collieries in South Wales. He was the principal originator and the chairman of the Lancashire Union Railways, started in 1866 and publicly opened at the end of 1869. From 1868 to 1874 he was one of the members of parliament for Wigan, and took a prominent part in connection with the Mines Regulation Bill, having previously held the office of president of the Mining Association of Great Britain. He became a Member of the Institution in 1863, and in 1864 gave a description of the Blake stone-breaking machine, which he had introduced at the Kirkless Hall Iron Works (Proceedings 1864, page 20); and in a discussion in 1867 (page 184) he gave some particulars of cost of sinking bore-holes. From 1871 he resided at Bilton Grange near Rugby; and having been placed on the commission of the peace for the county of Lancaster in 1865, was afterwards appointed deputy-lieutenant for Warwickshire. His death took place at his residence in London on 21st April 1884, in the sixty-ninth year of his age, after a brief illness.

Robert Lüthy, born at Solothurn in Switzerland on 24th September 1840, was the youngest son but one in a family of twenty-one children, his father, Victor Lüthy, being a veterinary surgeon. At an early age he showed a great liking and aptitude for mechanics; and after having passed through the schools of his native town, in which he received instruction in mechanics, mechanical drawing, mathematics, and kindred subjects, he was placed with the proprietor of a repairing establishment for smaller kinds of machines, clocks, and other articles. He thus acquired a practical knowledge of every detail of the machines and other objects under repair; and soon showed remarkable skill in handling tools, and also in working and shaping tin-plate and other sheet metal, continuing meanwhile to attend technical classes. At the age of sixteen he entered the engineering works of Messrs. Sulzer Brothers, Winterthur, where during the four years of his stay he received a thorough practical training, both in the drawing office and in the workshops, still continuing to attend evening classes in mechanics, mathematics, and other subjects. Early in

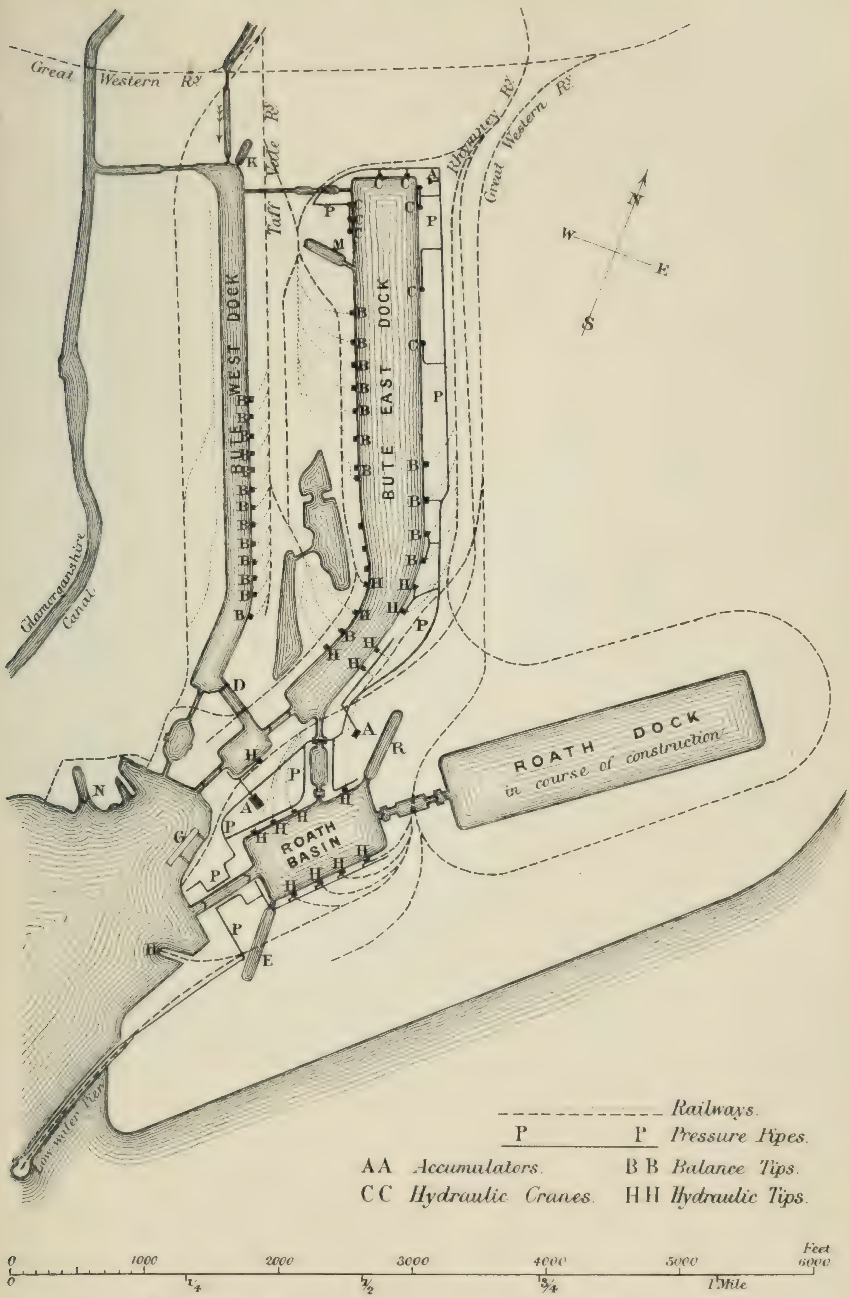
1862 he came to London, and at the close of the exhibition of that year was engaged as draughtsman by Messrs. R. and L. R. Bodmer. Some eighteen months later he entered the service of Messrs. Hick Hargreaves and Co. of Bolton, with whom he continued until his death, which took place on 3rd July 1884, at the age of forty-three. In the year 1863 he designed a hydraulic cotton-packing press, and a year or two later a variety of hydraulic balanced-valves; and in 1868 he brought out a new construction of hydraulic balanced-valve, which has been largely used in steel works and by makers of hydraulic machinery in this country and abroad. Along with Mr. Hick he carried out a series of experiments on the friction of leather collars used in hydraulic presses; and his name is mentioned as an authority on this subject by Rankine. About 1876, when Messrs. Hick Hargreaves and Co. commenced the manufacture of cold-air machines for freezing and preserving meat, Mr. Lüthy carried out a series of experiments at their works in Bolton, to determine the efficiency of cold-air machines on the system of injecting cold water into the compression cylinders, and of machines without injection, in which the air is cooled by contact with cold surfaces. He also carried out experiments on the efficiency of heat-exchangers in these machines, and to ascertain the quantity of heat transmitted through walls of different thicknesses and of different materials, used for insulating the cold rooms to contain frozen meat in ships and in stores. In June 1883 he went to Australia on business connected with the shipping of frozen meat, and to inspect the machinery made in Bolton for a large freezing establishment there. After an absence of a little more than a year he got back to Bolton apparently in good health on the evening of 2nd July 1884; but his death took place very suddenly from heart disease early next morning. He became a Member of the Institution in 1878.

John Proctor Woodhead was born at Ovenden near Halifax on 5th September 1843, and served his time at the works of Messrs. Joseph Whitworth and Co., Chorlton Street, Manchester, under Mr. William W. Hulse, acquiring a good practical knowledge of mechanical drawing and construction. Subsequently he was for

several years in the service of Mr. Hulse, engaged professionally in engineering work and valuations. About ten years ago he commenced business in Manchester on his own account, as consulting engineer and valuer, and afterwards also as assessor of fire losses for insurance companies; in the latter capacity he acquired the highest reputation for able, judicious, and honourable assessment. His death took place on 16th July 1884, in the forty-first year of his age, when he was one of the passengers killed in the railway accident at Penistone. He became a Member of the Institution in 1873. He was a Member of the Manchester Insurance Institute, and for two years chairman of the Manchester Association of Employers, Foremen, and Draughtsmen.

CARDIFF DOCKS. *Plate 28.*

Fig. 1. *Plan of Bute Docks.*



(Proceedings Inst. M.E. 1884) Scale 1440 feet per inch.

CARDIFF DOCKS.

Public Graving Dock

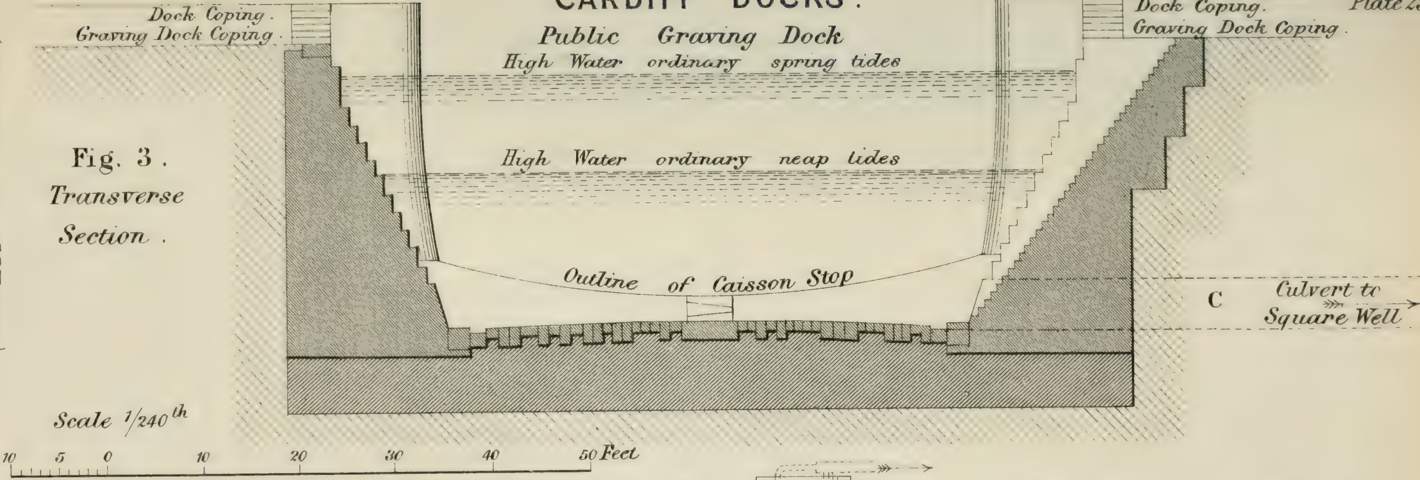
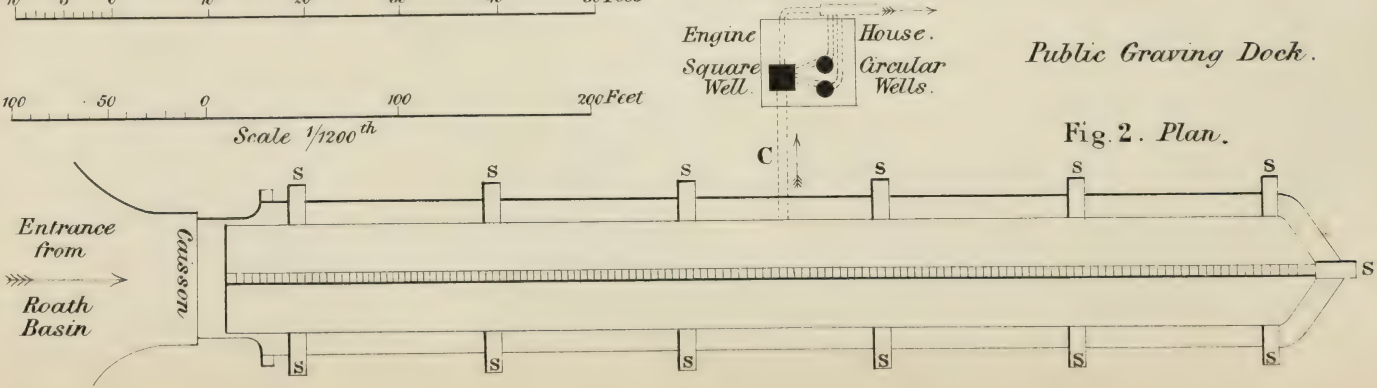


Fig. 3. Transverse Section.



Public Graving Dock.

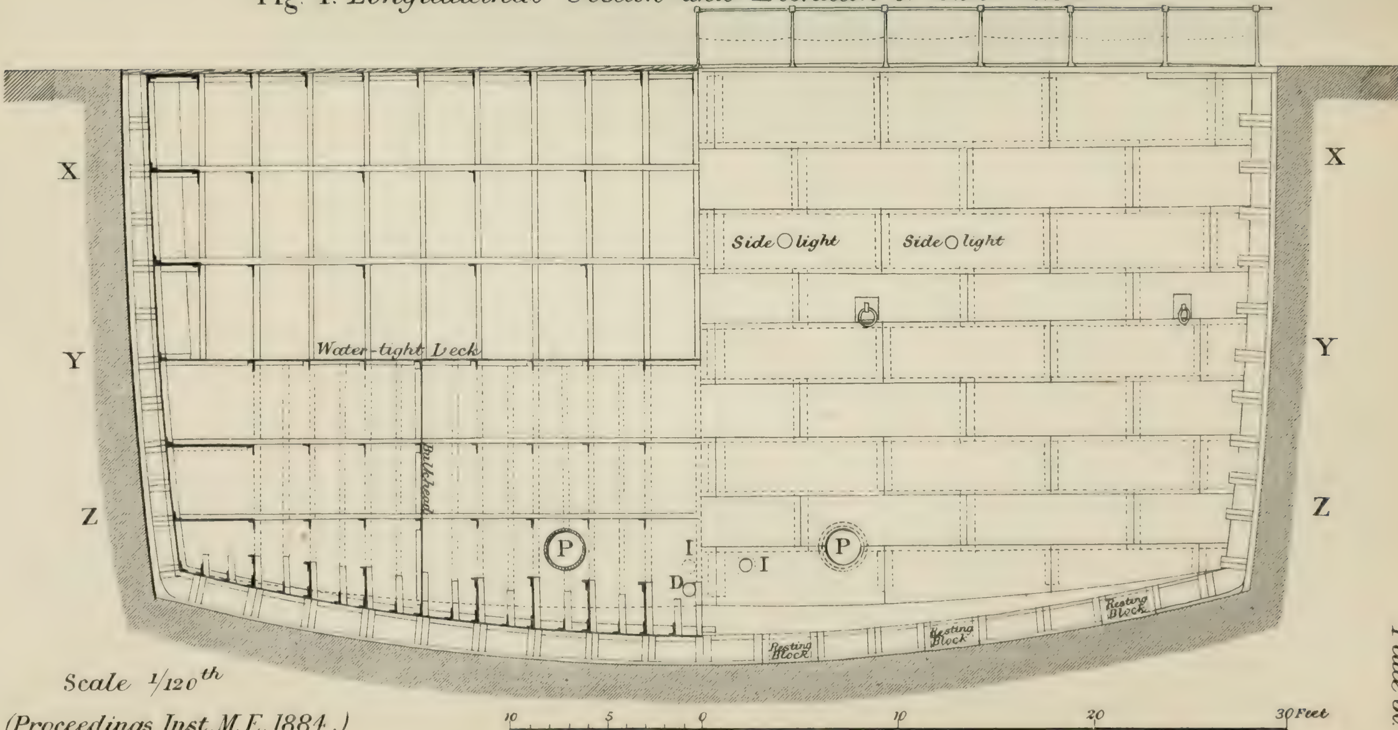
Fig. 2. Plan.

(Proceedings Inst. M.E. 1884.)

CARDIFF DOCKS.

Caisson of Public Graving Dock.

Fig. 4. *Longitudinal Section and Elevation of outer face.*



Scale 1/120th

(Proceedings Inst. M. E. 1884.)

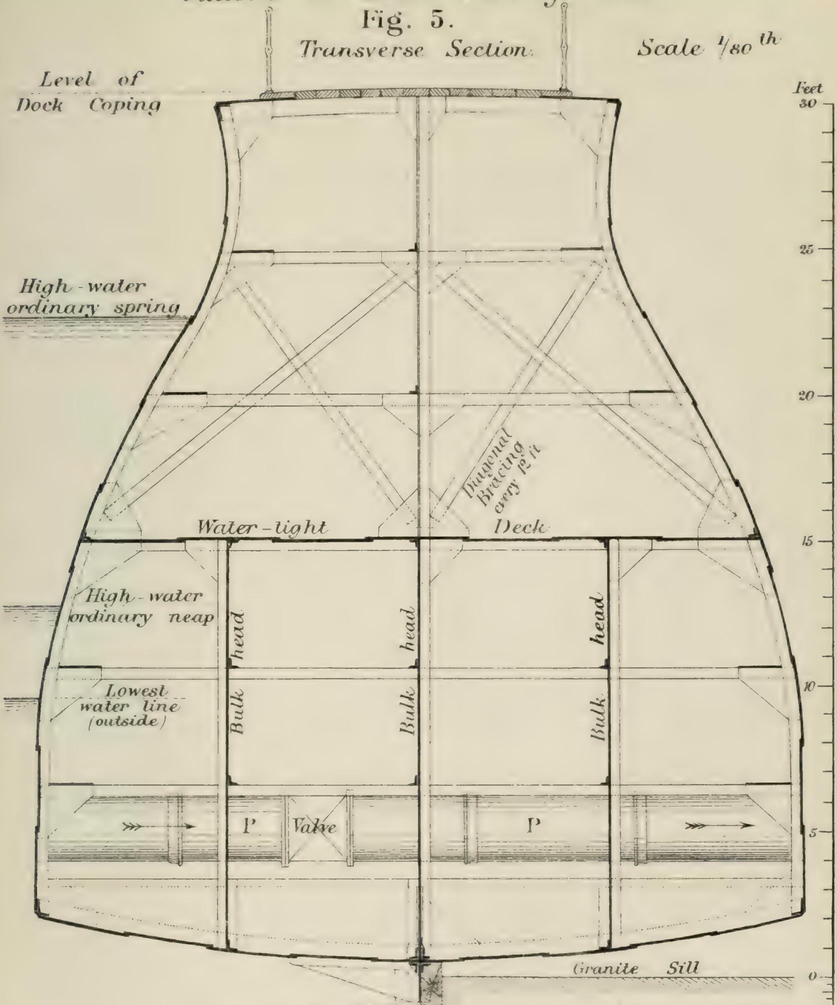
Plate 30.

CARDIFF DOCKS. *Plate 31.*

Caisson of Public Graving Dock.

Fig. 5.

Transverse Section. *Scale 1/80th*



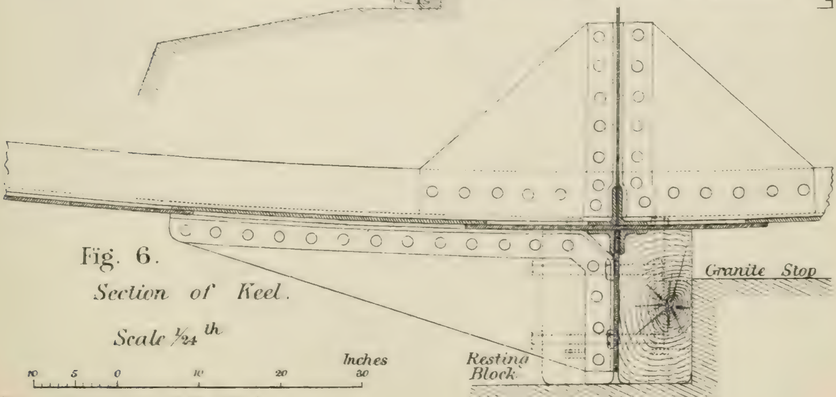


Fig. 6.

Section of Keel.

Scale 1/24th

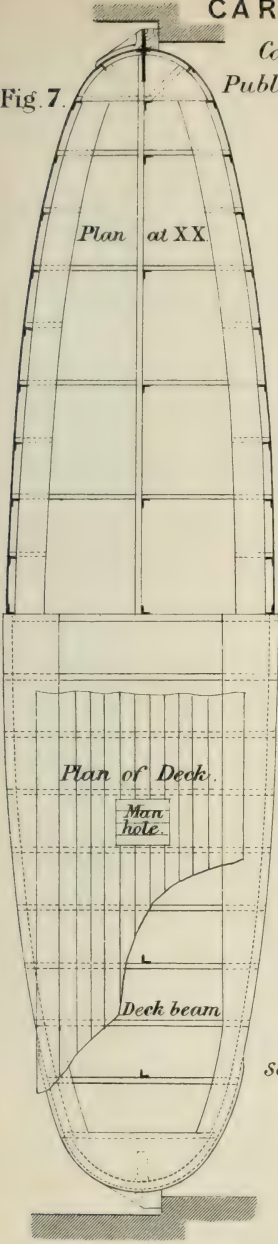
(Proceedings Inst. M.E. 1884.)

CARDIFF DOCKS.

Caisson of Public Graving Dock

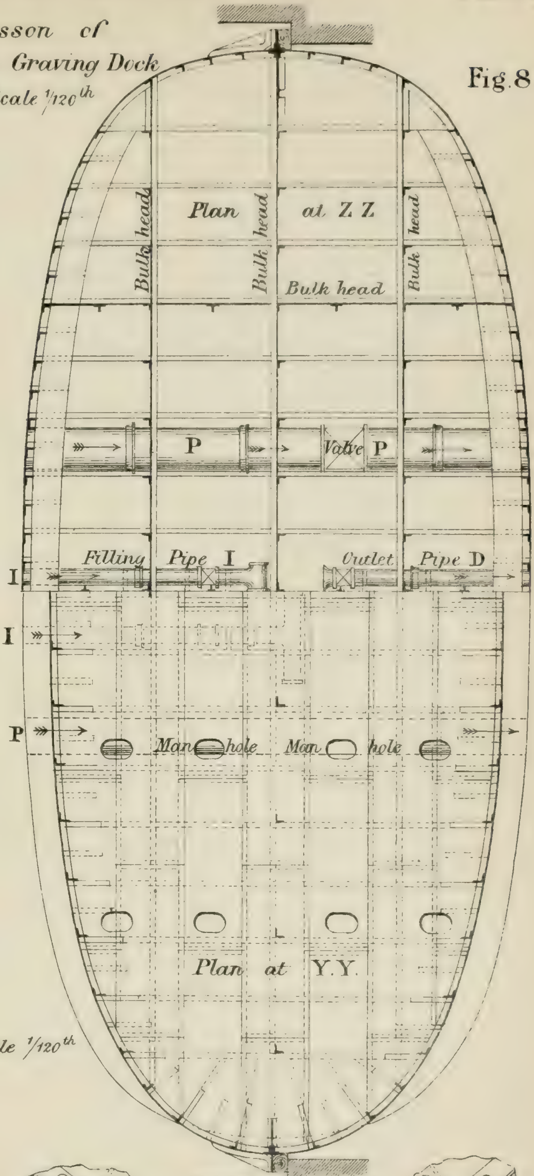
Scale 1/120th

Fig. 7.



Scale 1/120th

Fig. 8.



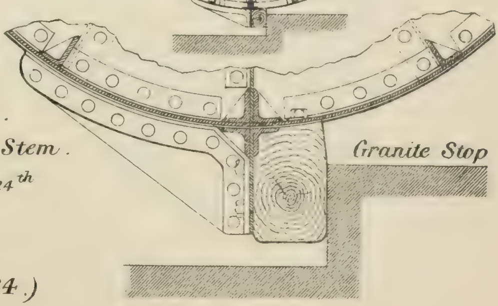


Fig. 9.

Plan of Stem.

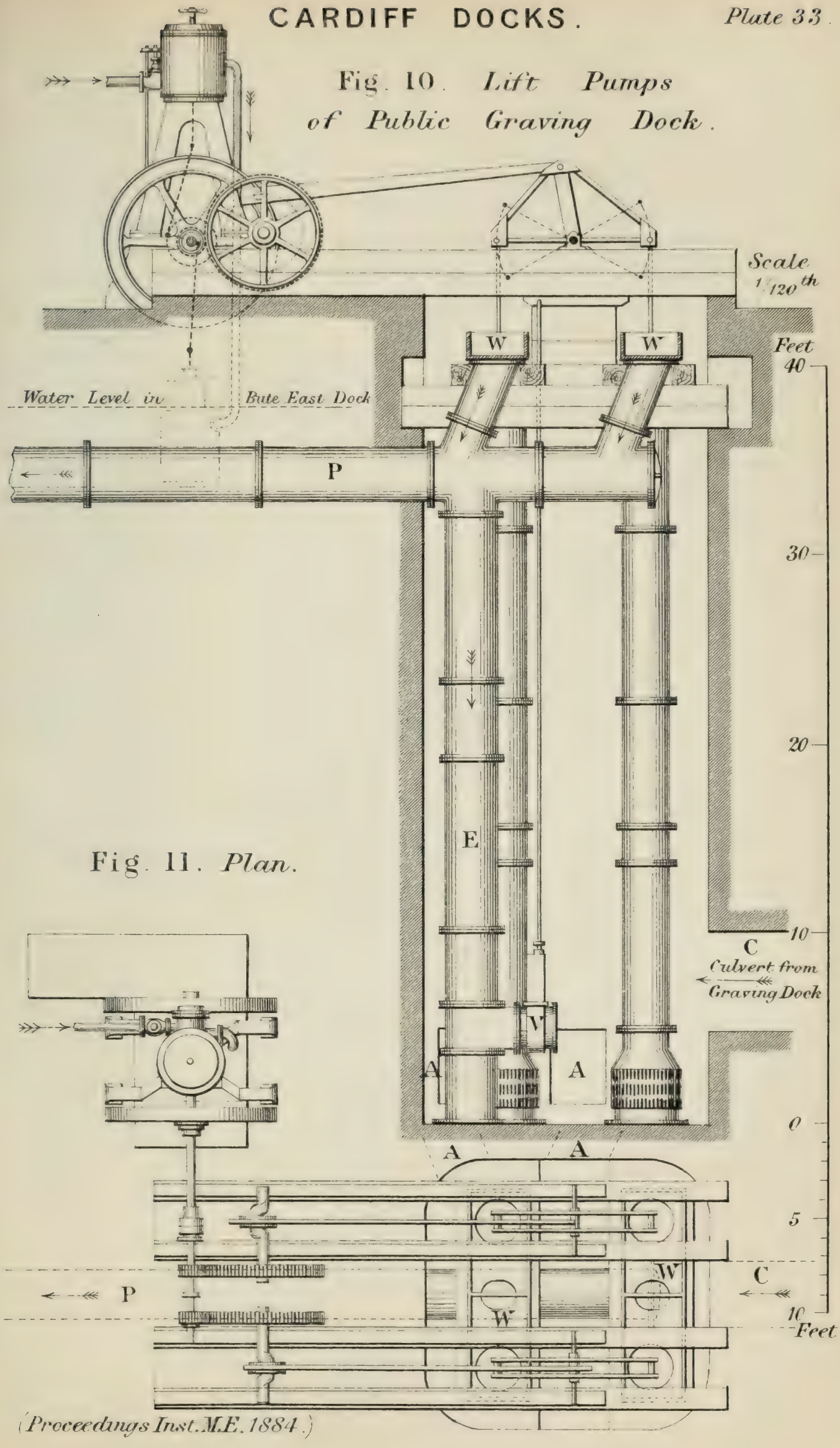
Scale 1/24th

CARDIFF DOCKS.

Plate 33.

Fig. 10. *Lift Pumps of Public Graving Dock.*

Fig. 11. *Plan.*



(Proceedings Inst. M.E. 1884.)

CARDIFF DOCKS.

Fig. 12. *Centrifugal Pumps of Public Graving Dock.*

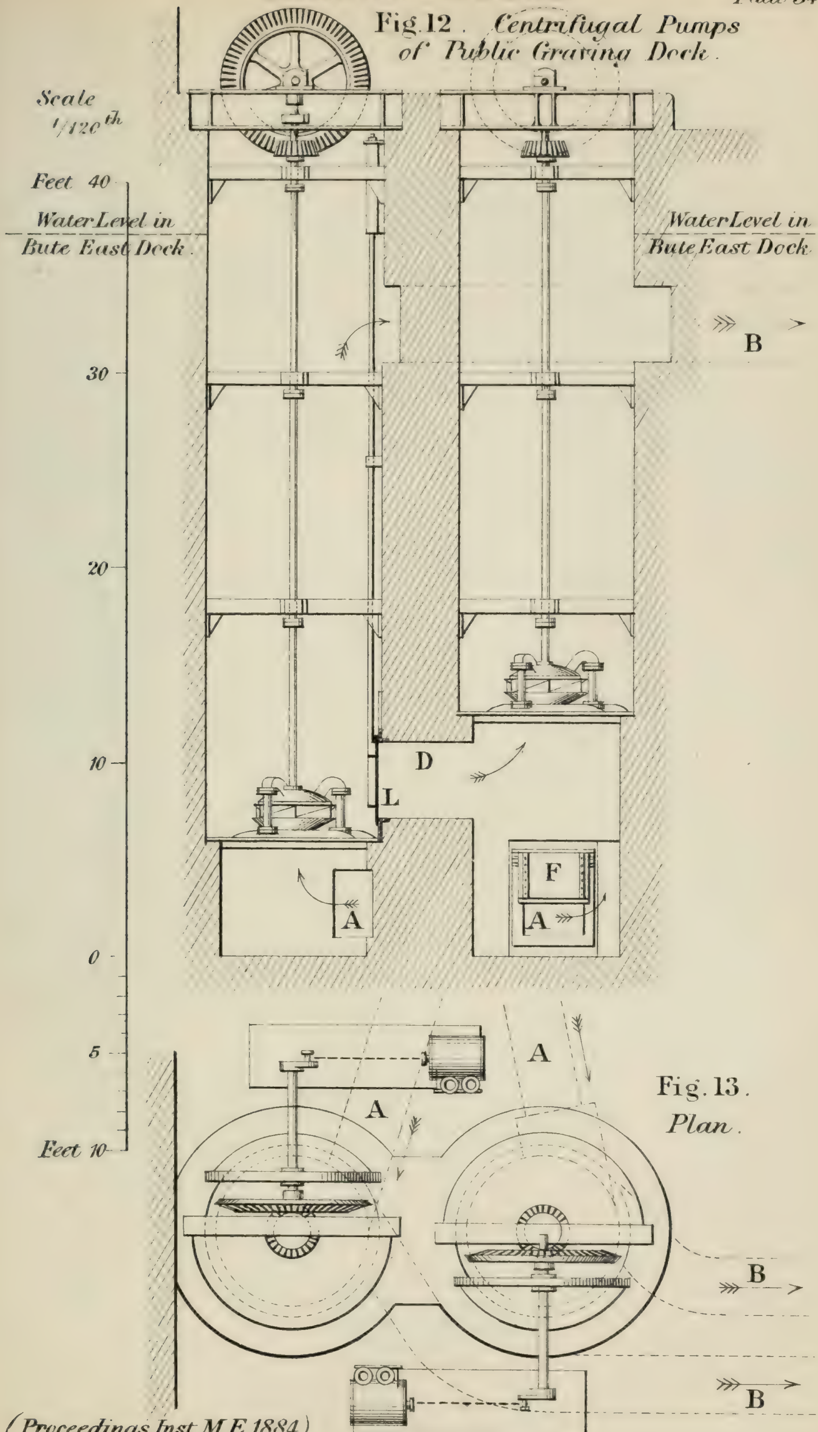


Fig. 13. *Plan.*

(Proceedings Inst. M.E. 1884)

CARDIFF DOCKS. *Plate 35.*

Centrifugal Pump of Public Graving Dock.

Fig. 14. *Vertical Section.* *Scale 1/24th*

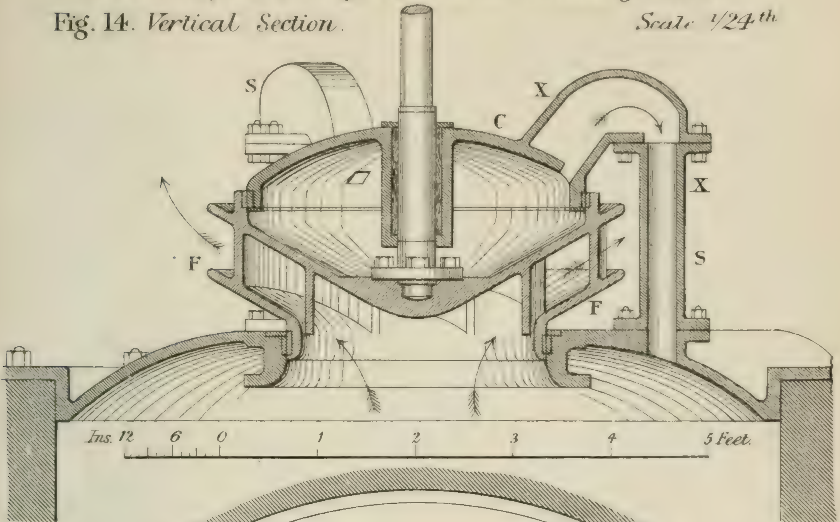
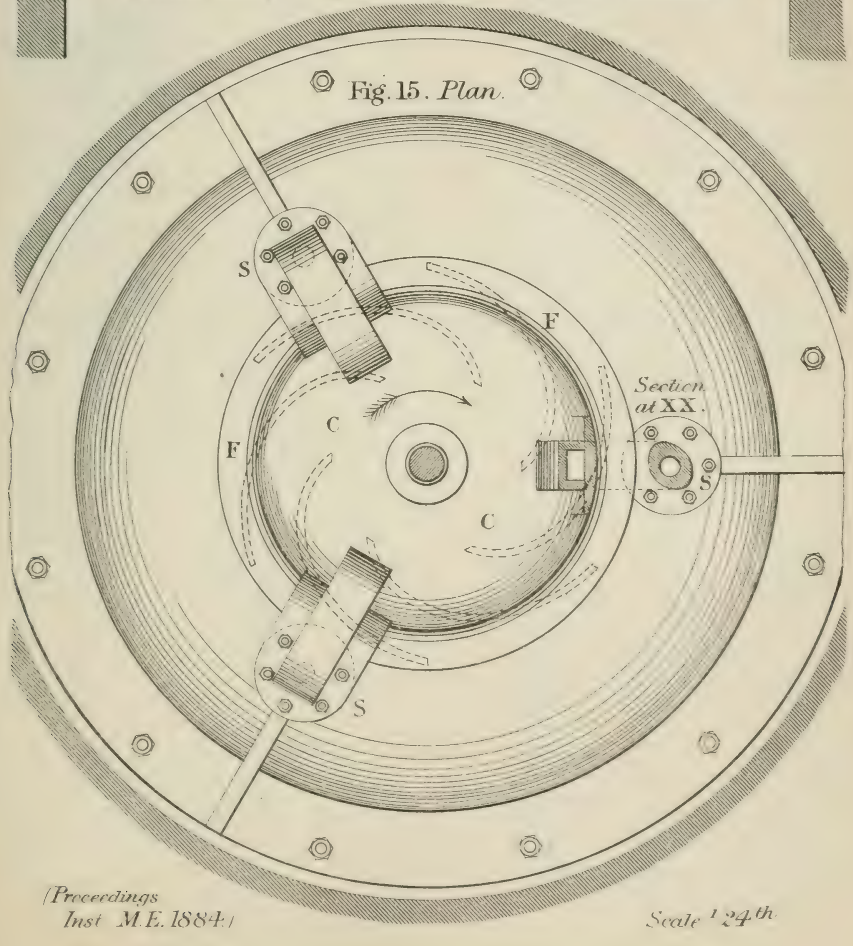
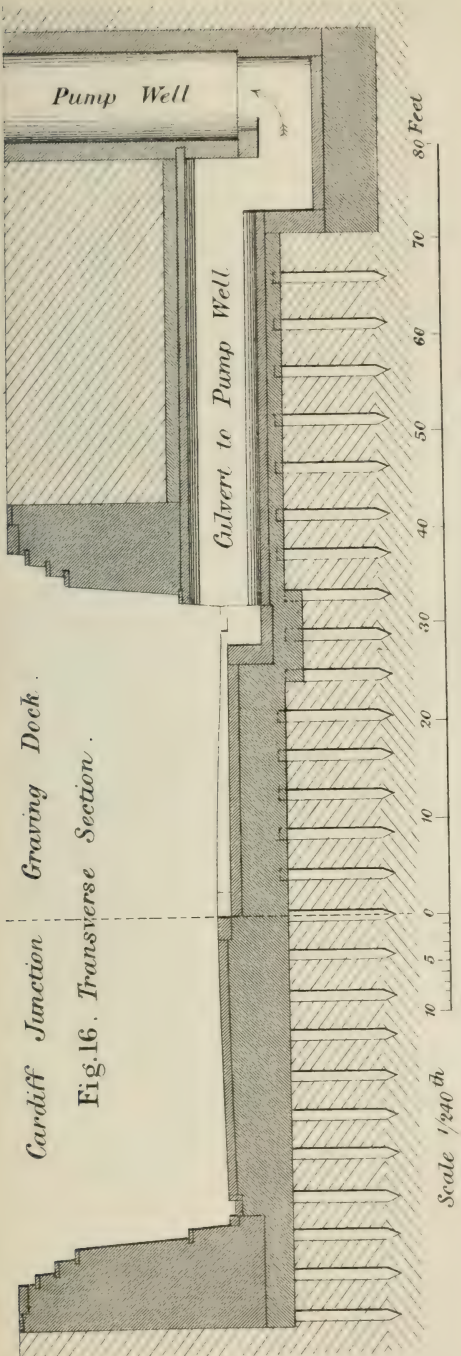


Fig. 15. *Plan.*



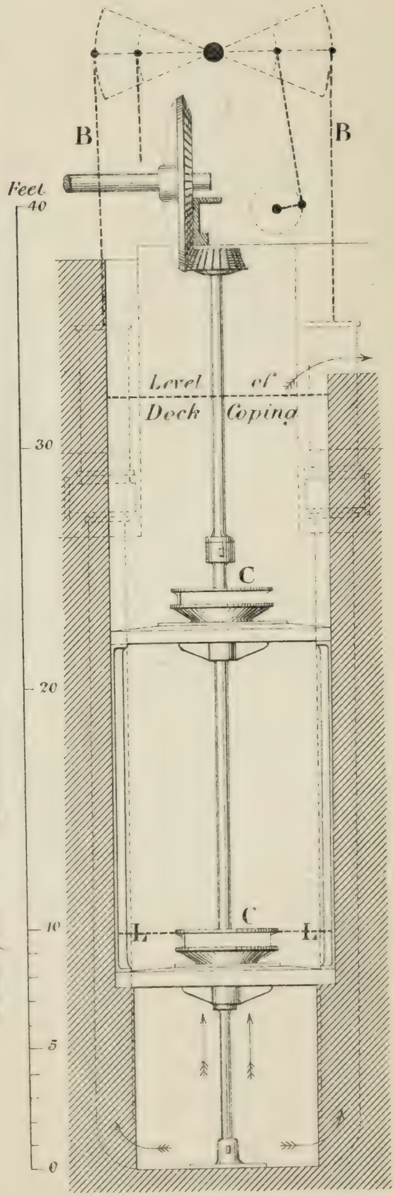
(Proceedings Inst. M.E. 1884.) *Scale 1/24th*

Cardiff Junction Graving Dock.



Cardiff Junction Graving Dock.
Fig.16. Transverse Section.

Fig.17. *Pump Well with Centrifugal and Bucket Pumps.*
Scale 1/100th



CARDIFF DOCKS.

Caisson of Cardiff Junction Graving Dock.

Fig. 18. Side Elevation and Longitudinal Section.

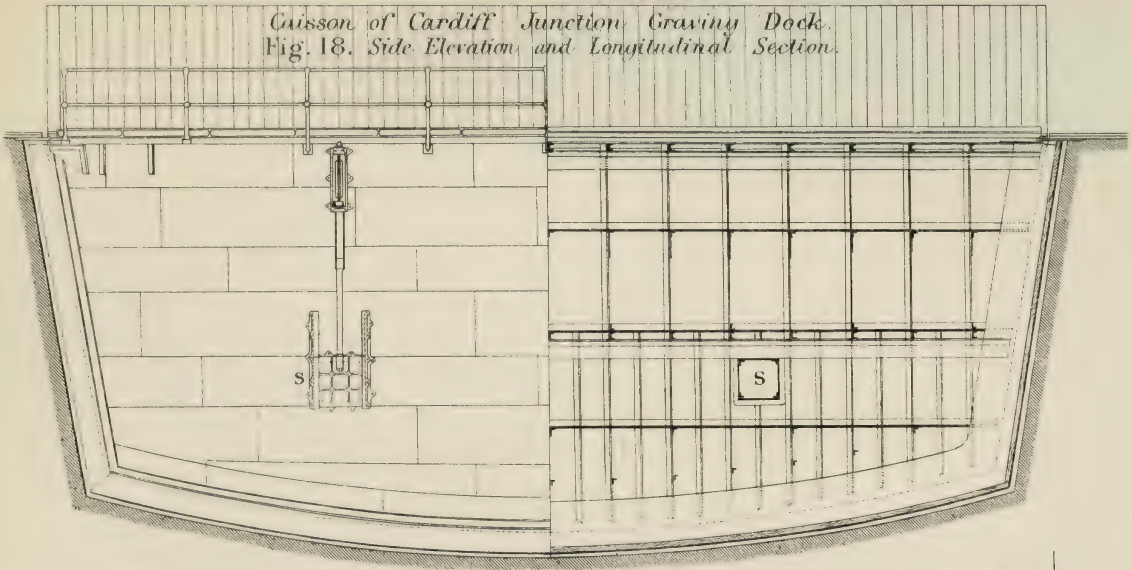
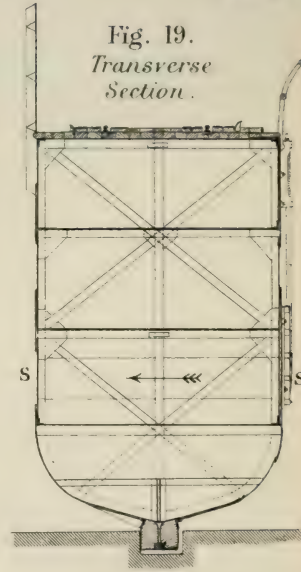


Fig. 19. Transverse Section.



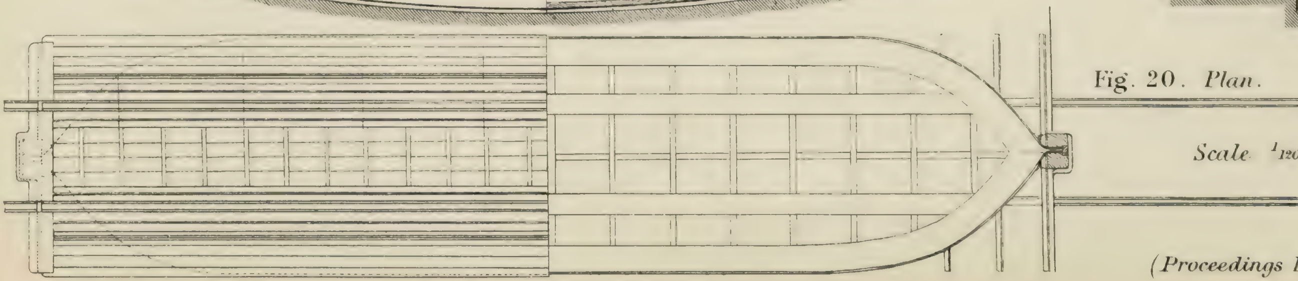


Fig. 20. Plan.

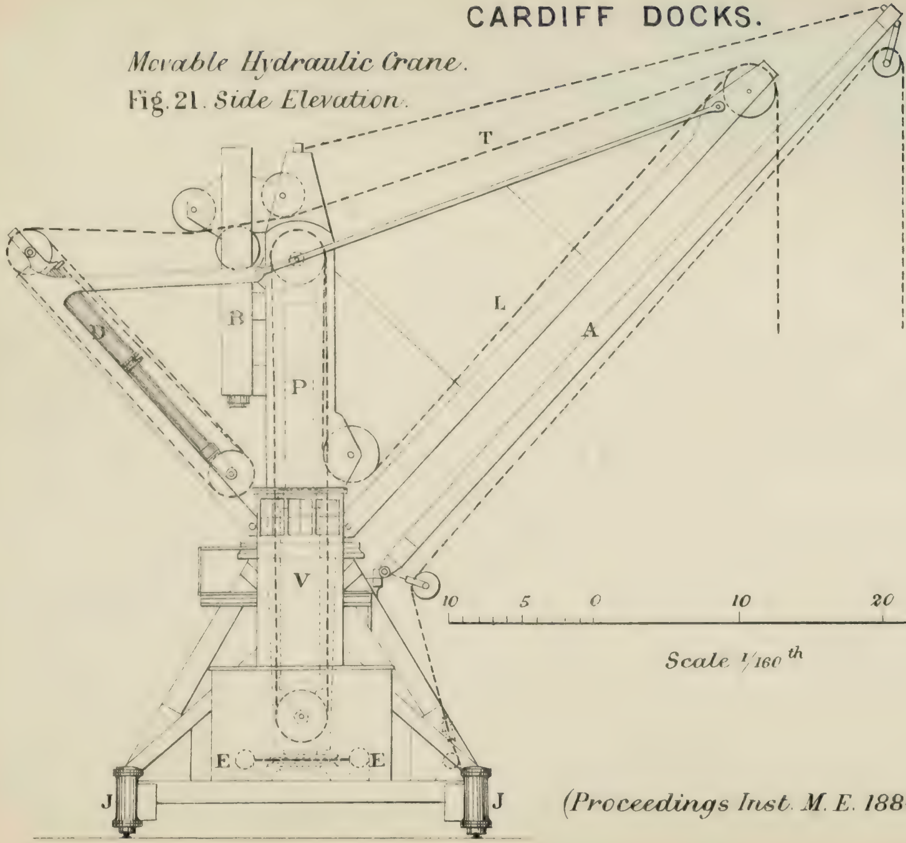
Scale $^{1}/_{120}{}^{th}$

Plate 37.

CARDIFF DOCKS.

Movable Hydraulic Crane.

Fig. 21. *Side Elevation.*



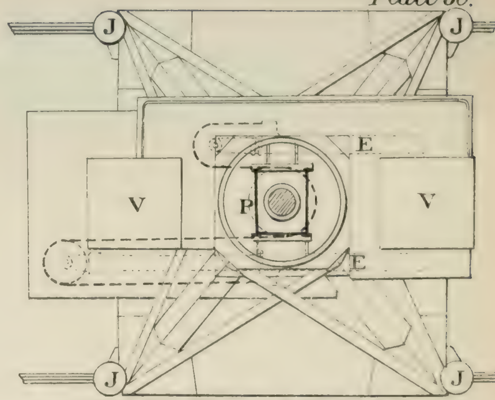
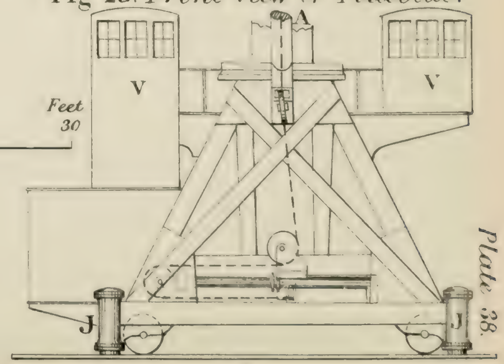


Fig. 22. *Plan of Pedestal.*

Fig 23. *Front view of Pedestal.*



Feet

10 5 0 10 20 30

Scale 1/160 th

(Proceedings Inst. M. E. 1884.)

Plate 38.

CARDIFF DOCKS.

Movable Hydraulic Crane.

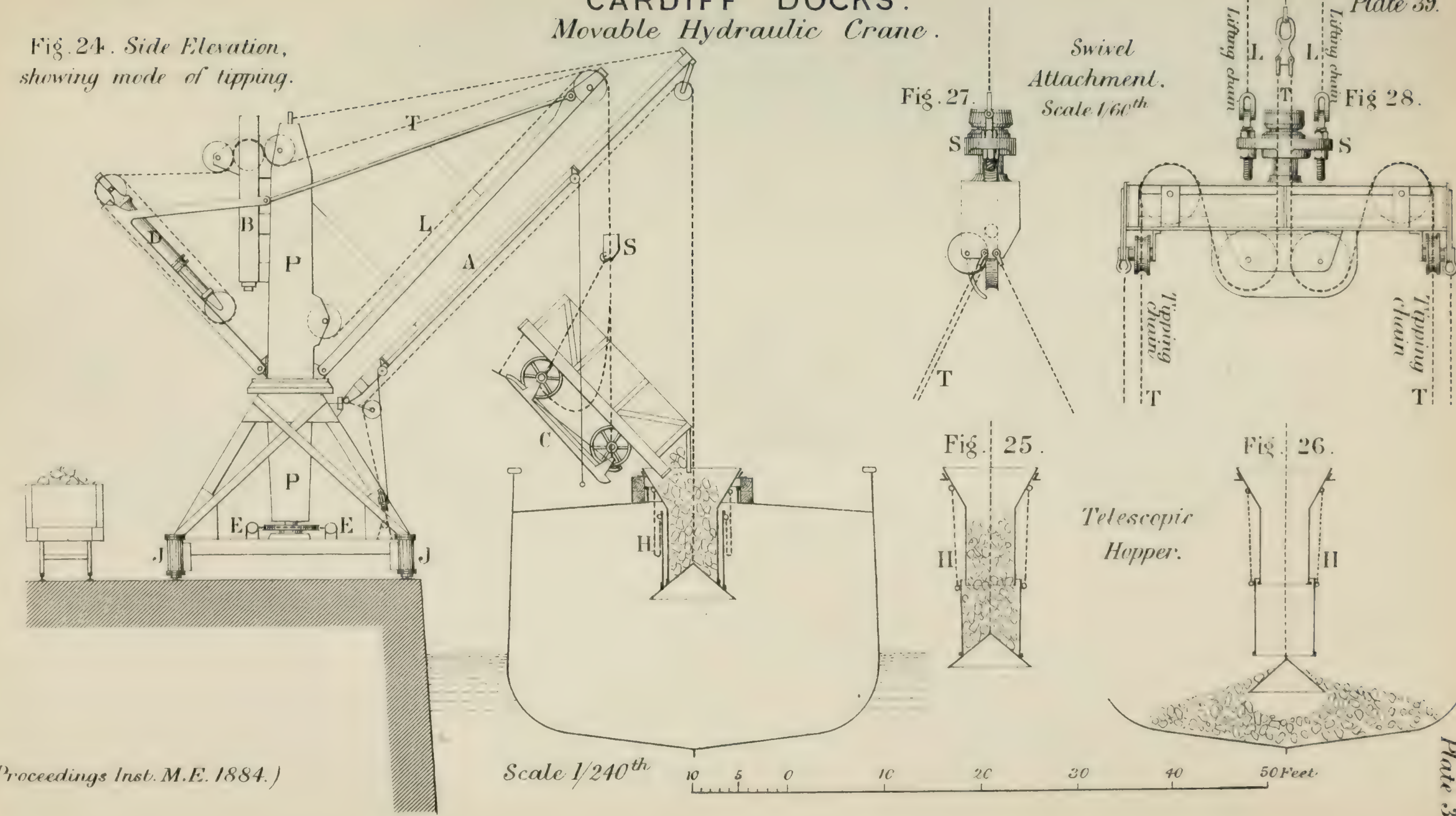


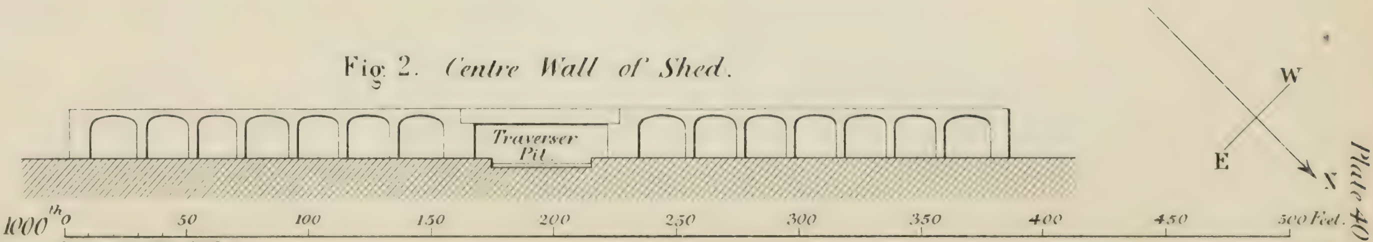
Fig. 24. Side Elevation, showing mode of tipping.

(Proceedings Inst. M.E. 1884.)

LOCOMOTIVE RUNNING SHED.

Fig. 1. *Plan of Running Shed.*

Fig. 2. *Centre Wall of Shed.*



(Proceedings Inst. M. E. 1884.)

Plate 40

LOCOMOTIVE RUNNING SHED.

Fig. 3. *General Plan of Running Shed and Yard.* Scale 1/3000th

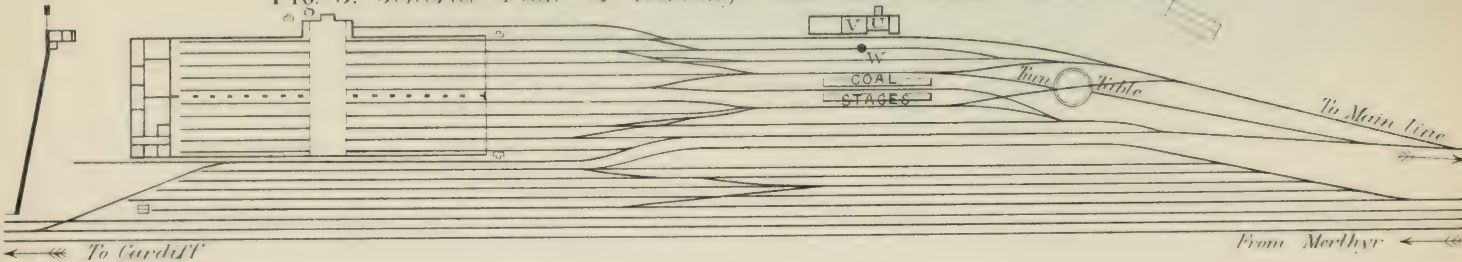
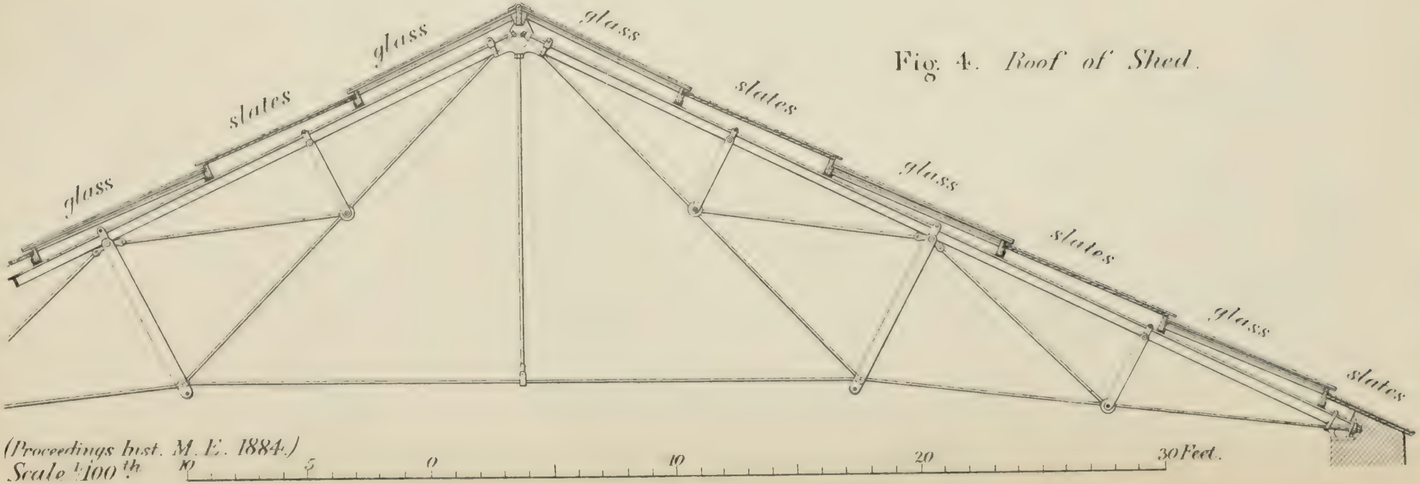


Fig. 4. *Roof of Shed.*

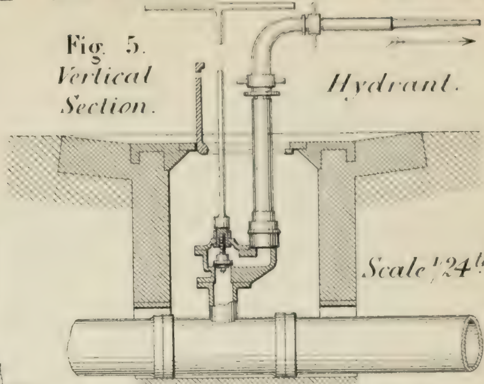


(Proceedings Inst. M. E. 1884.)
Scale 1/100th

LOCOMOTIVE RUNNING SHED. *Plate 42.*

Water Jet in Drop Pit. Scale 1/8th.

Fig. 5. *Vertical Section.* *Hydrant.*



Scale 1/24th.

Fig. 6. *Plan.*

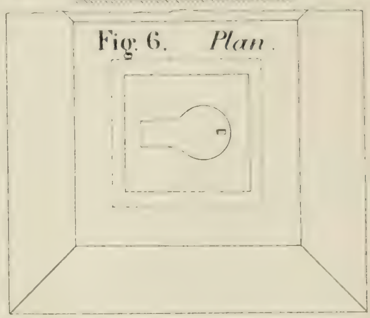


Fig. 7. *Sectional Plan.*

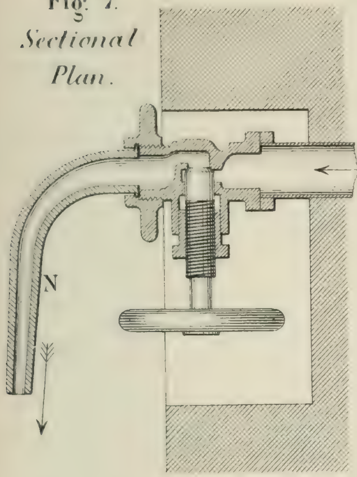
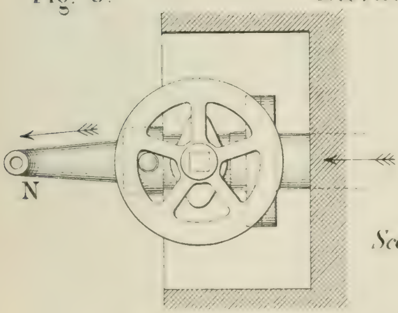


Fig. 8. *Elevations.* Fig. 9.



Scale 1/8th.

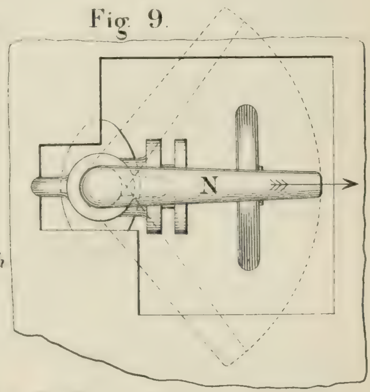
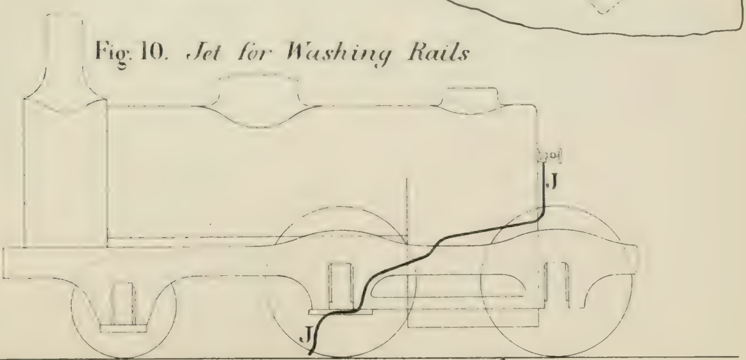


Fig. 10. *Jet for Washing Rails*



 Scale 1/80th.

LOCOMOTIVE RUNNING SHED. *Plate 43.*

Turntable.

Fig. 11. *Transverse Section.*

Scale 1/48th

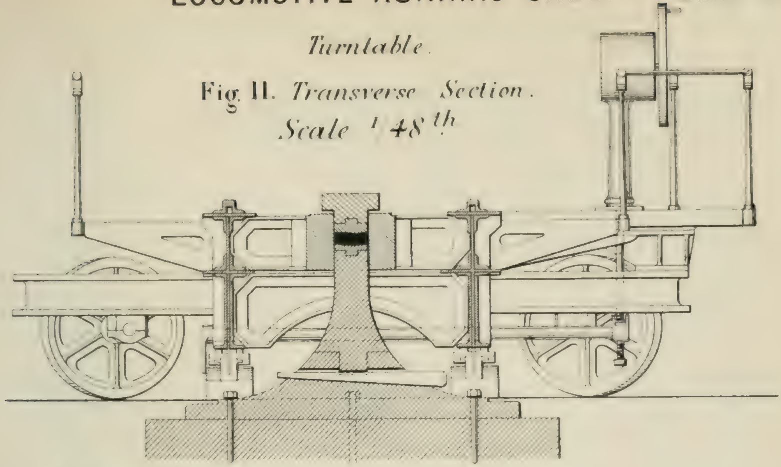


Fig. 13. *Centre Pivot.*

Scale 1/8th

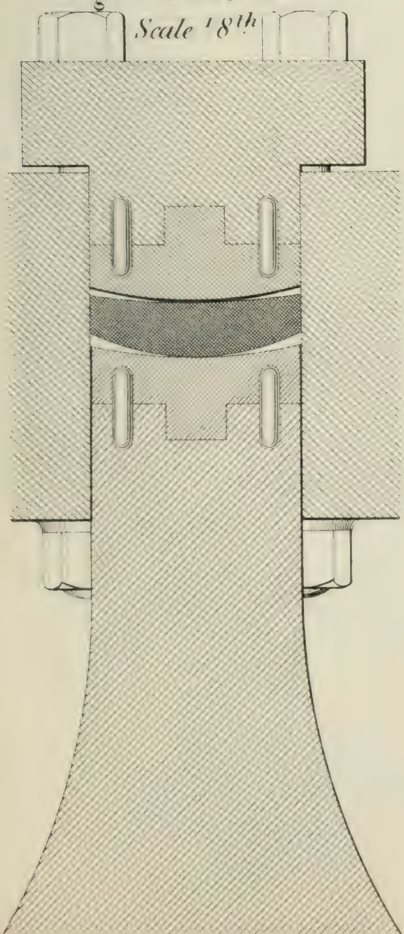


Fig. 12. *End of Table.*

Scale 1/48th

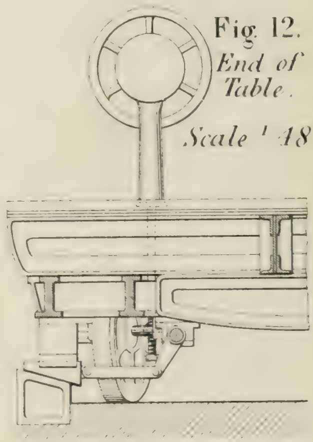


Fig. 14. *Section of Race.*

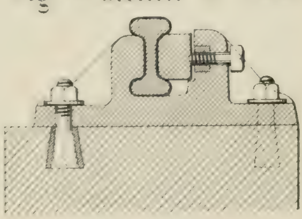
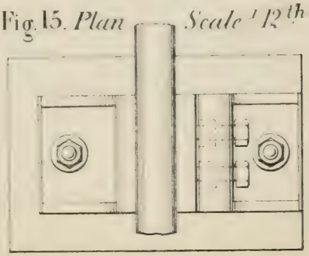


Fig. 15. *Plan* *Scale 1/12th*

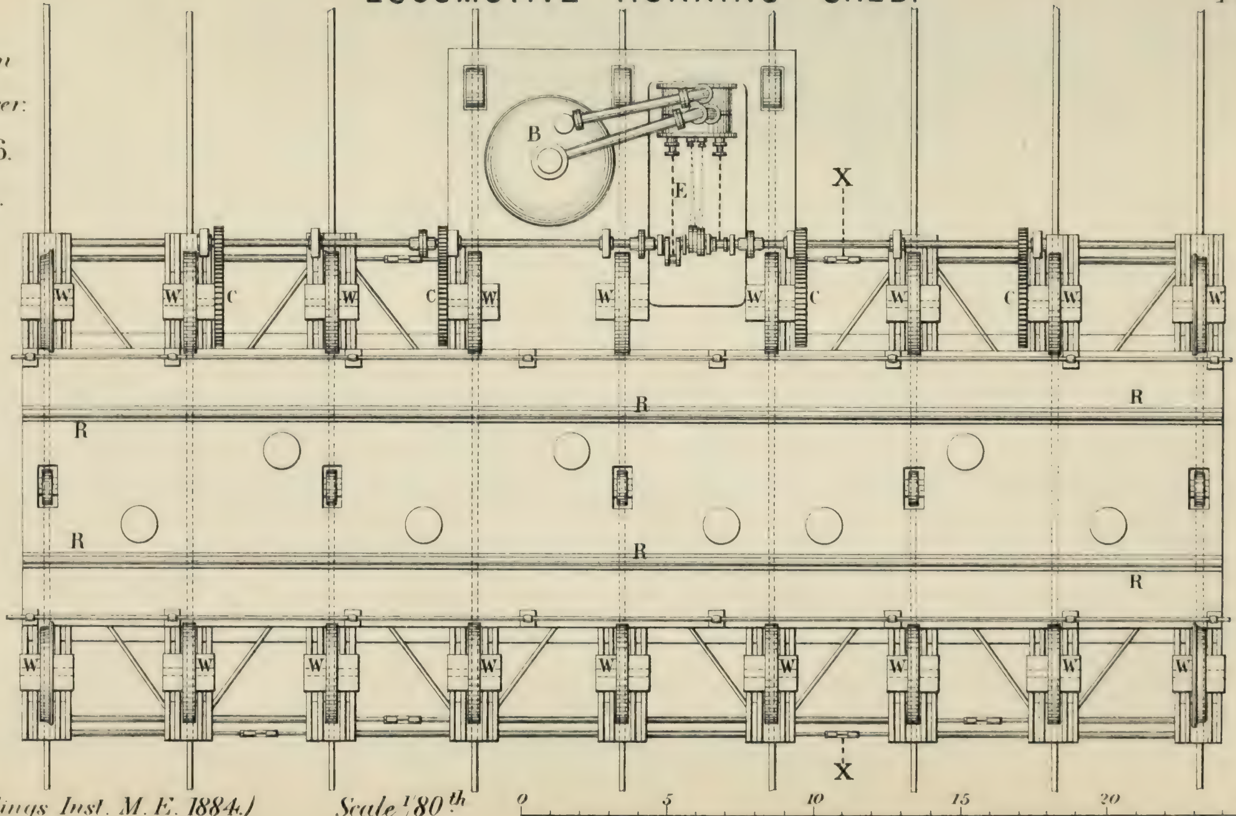


LOCOMOTIVE RUNNING SHED.

Steam Traverser:

Fig. 16.

Plan.



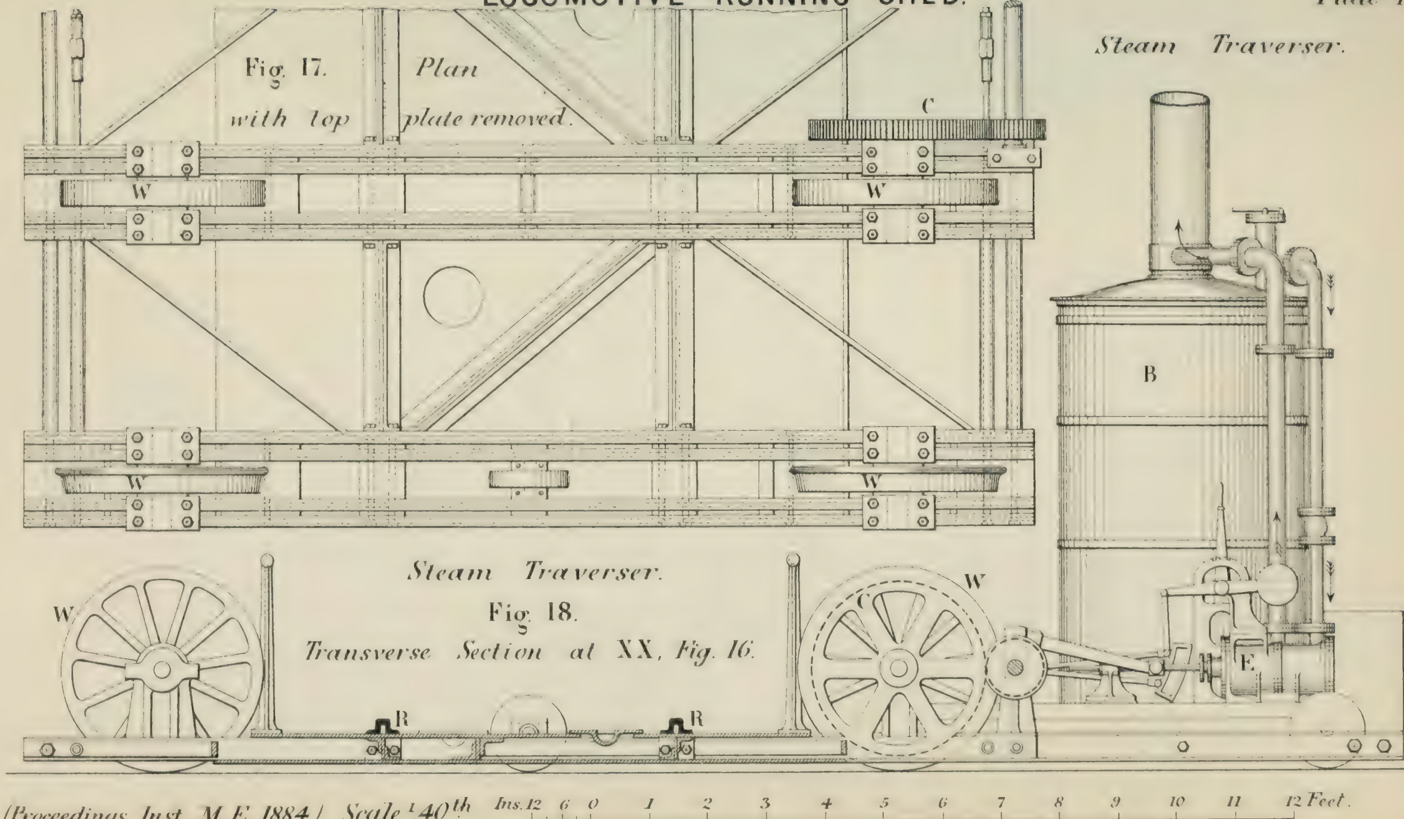
Scale 1/80th.

(Proceedings Inst. M. E. 1884.)

Plate 44.

LOCOMOTIVE RUNNING SHED.

Steam Traverser.

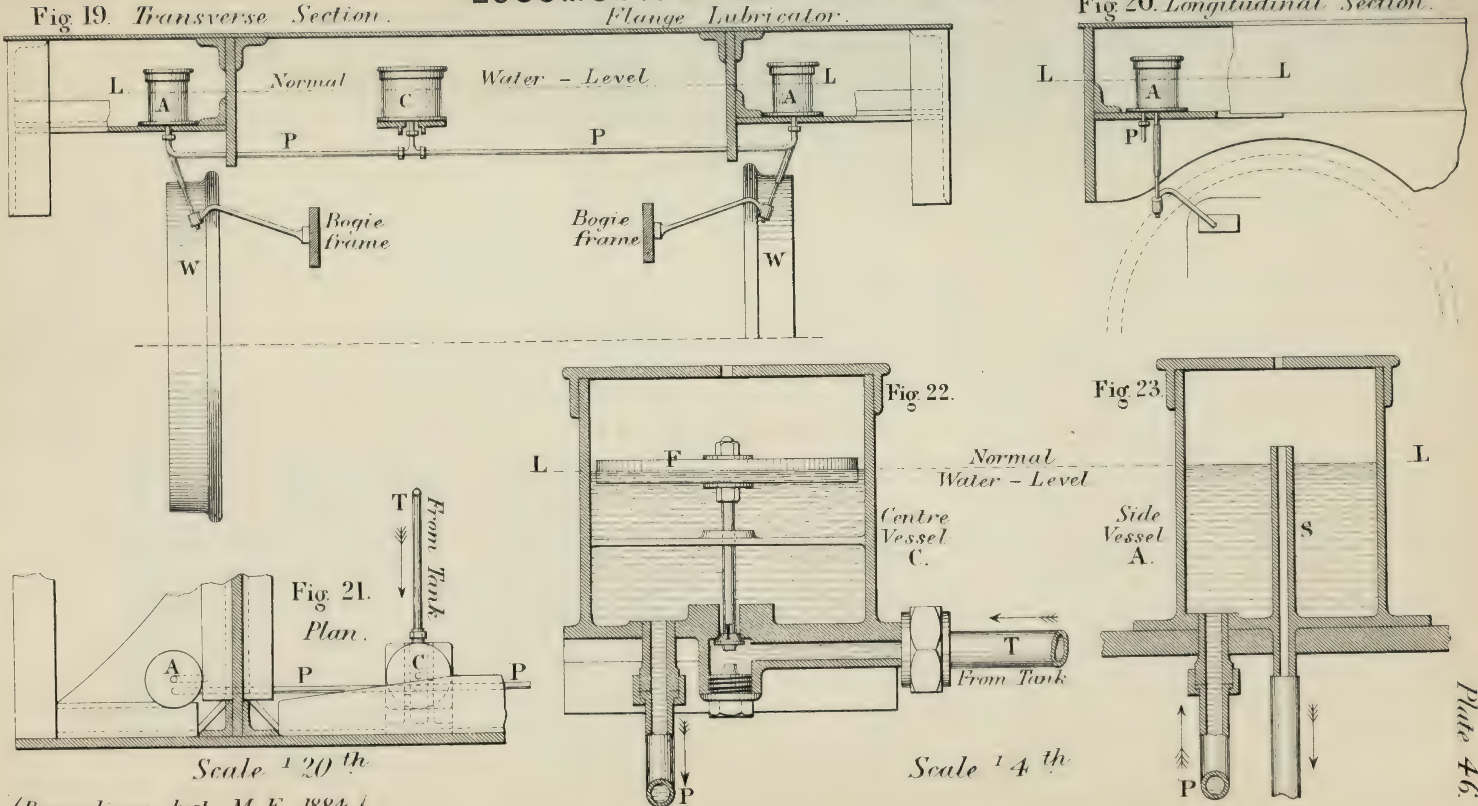


(Proceedings Inst. M.E. 1884.) Scale 1/40th

Plate 45.

LOCOMOTIVE RUNNING SHED.

Flange Lubricator.



(Proceedings Inst. M. E. 1884.)

Air Compressor.

Fig. 24. *Side Elevation.*

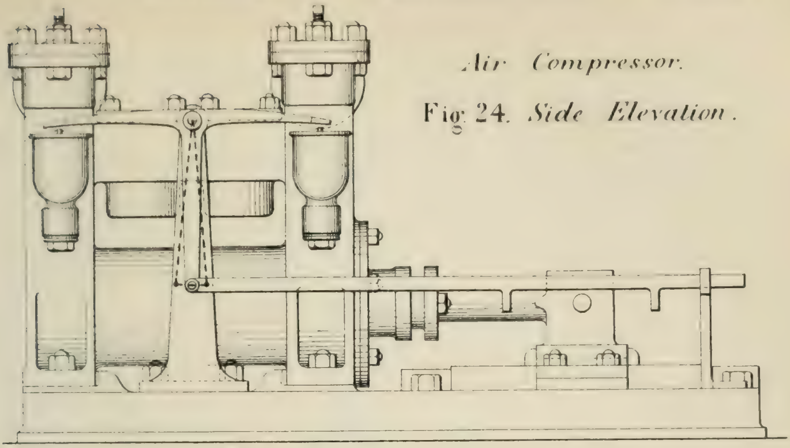


Fig. 25. *Longitudinal Section.*

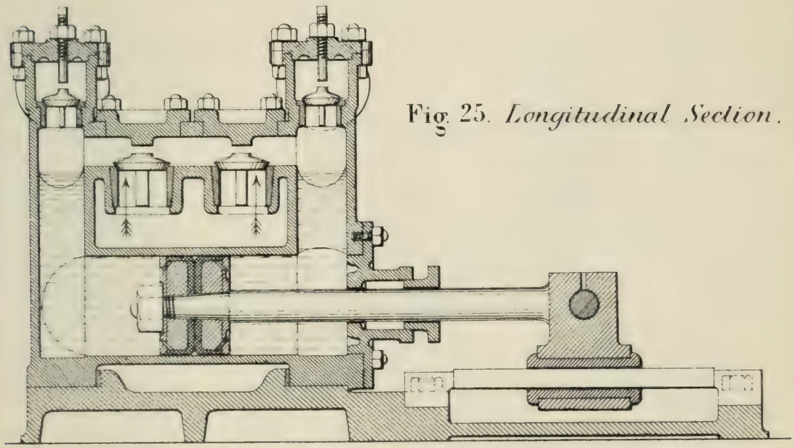


Fig. 26. *End Elevation.*

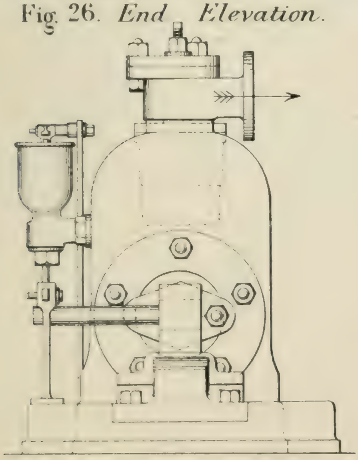
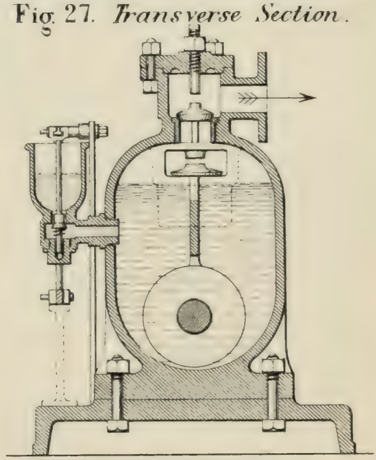


Fig. 27. *Transverse Section.*



Scale 1/8th 0 5 10 15 20 *Inches*

(Proceedings Inst. M. E. 1884.)

Scale 1/48th

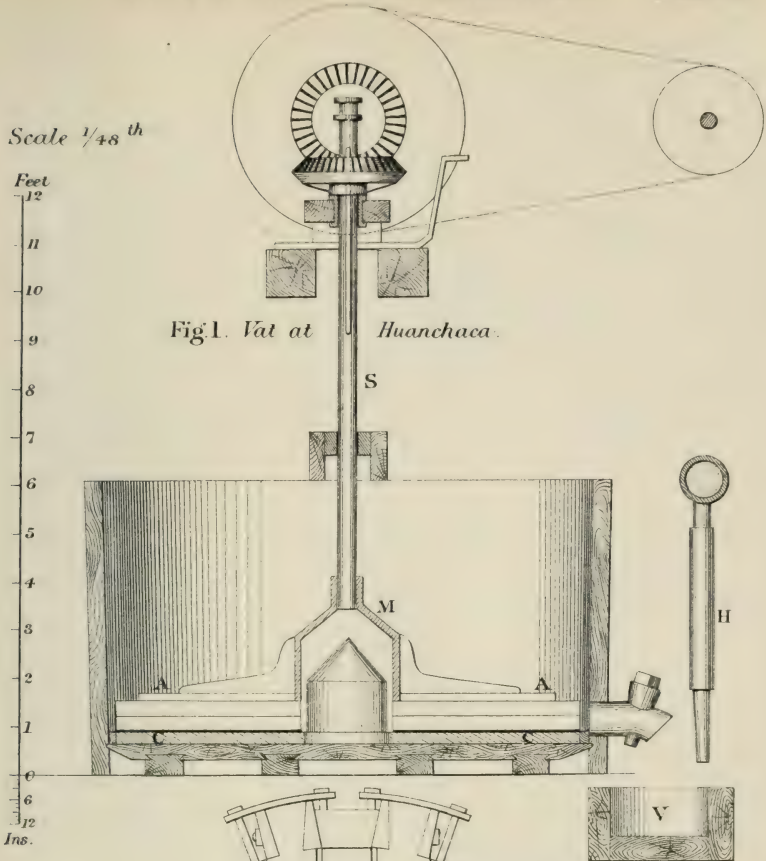


Fig. 1. *Vat at Huanchaca.*

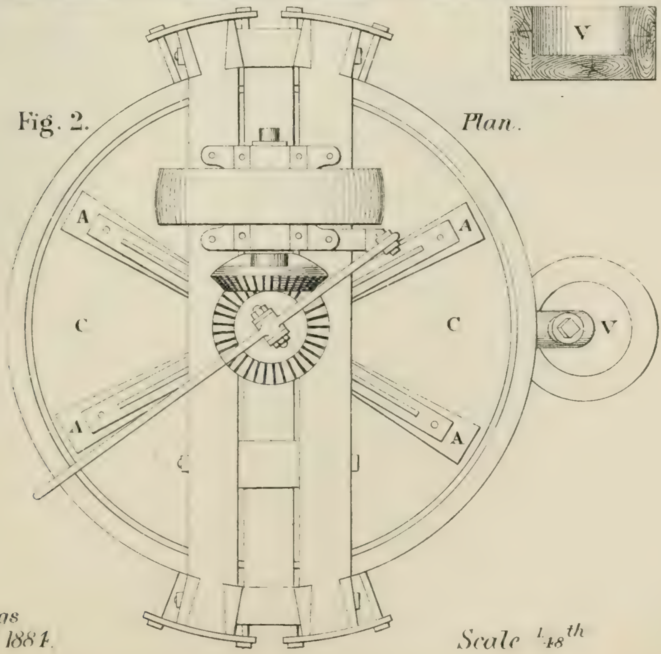


Fig. 2. *Plan.*

Scale 1/48th

Fig. 3. Vat at Guadalupe.

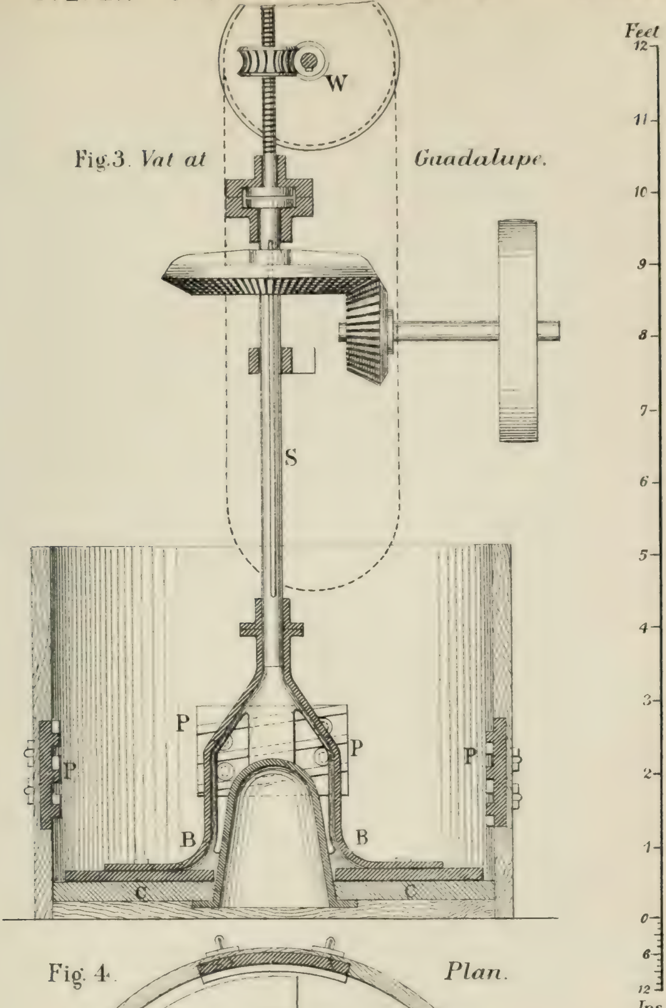
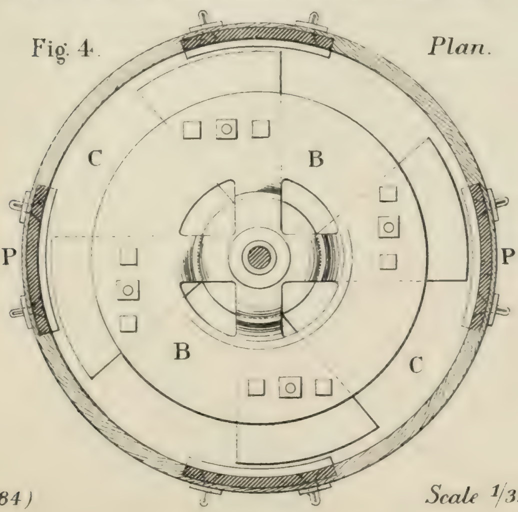


Fig. 4. Plan.



(Proceedings Inst. M. E. 1884)

Scale 1/32nd

Fig. 5. *Subliming Furnace.*

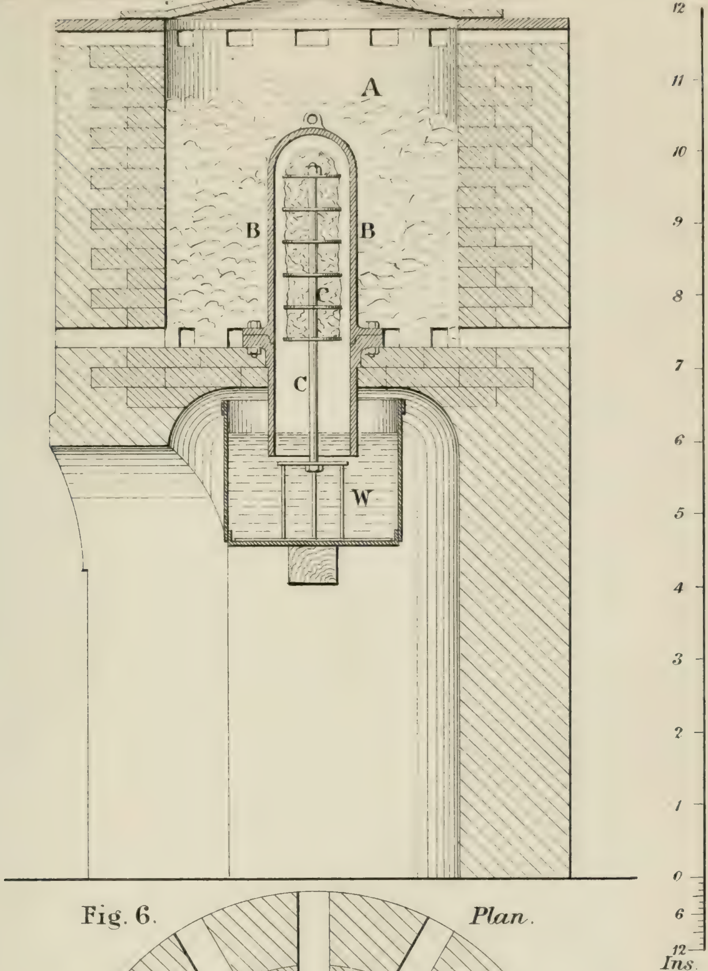
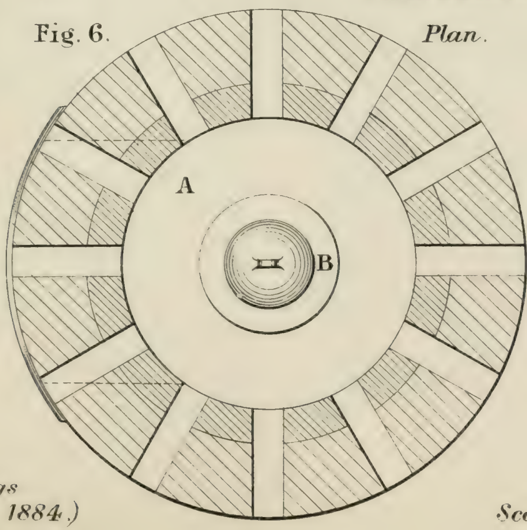


Fig. 6. *Plan.*



Scale 1/32nd

PETROLEUM FUEL IN LOCOMOTIVES.

Grazi and Tsaritsin Railway. South Russia. Tsaritsin to Archeda.

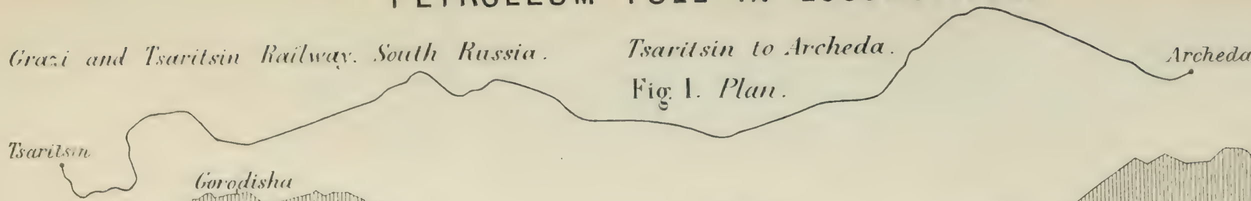


Fig. 1. Plan.

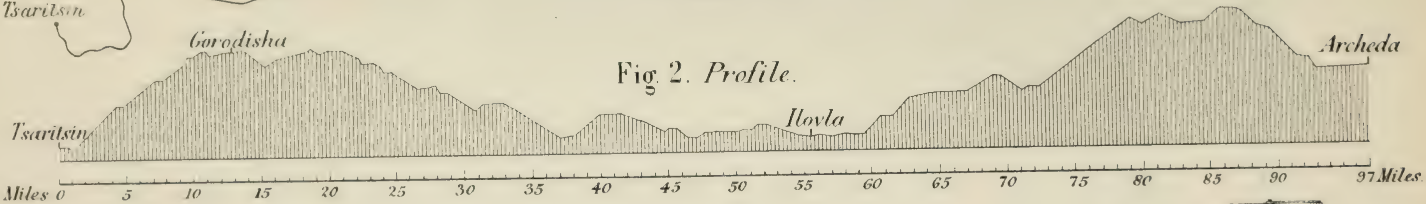
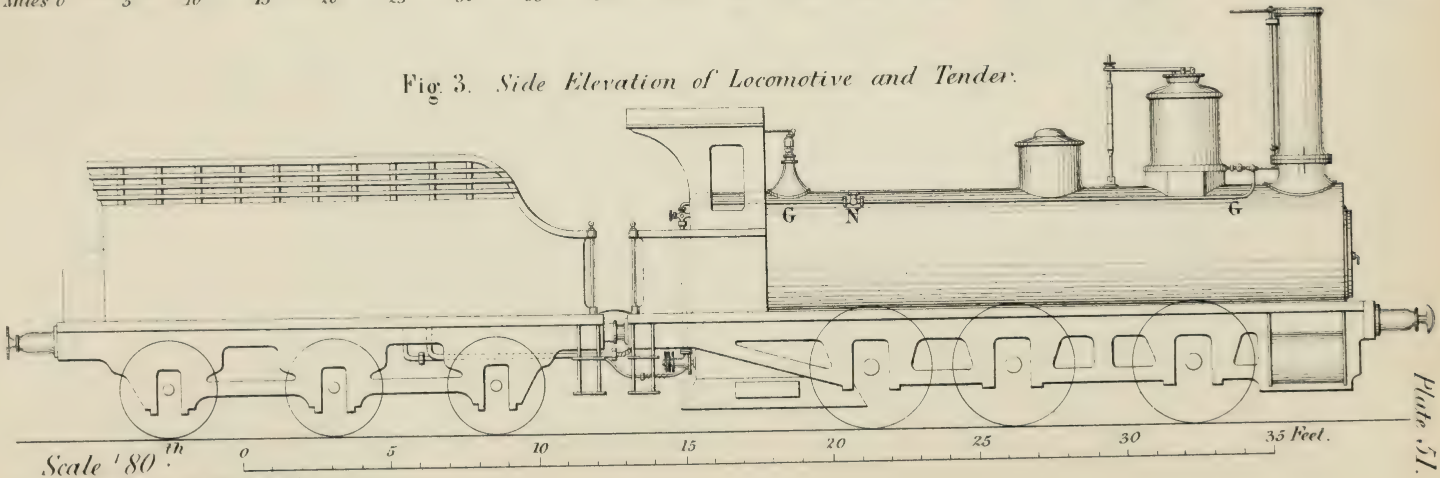


Fig. 2. Profile.

Fig. 3. Side Elevation of Locomotive and Tender.



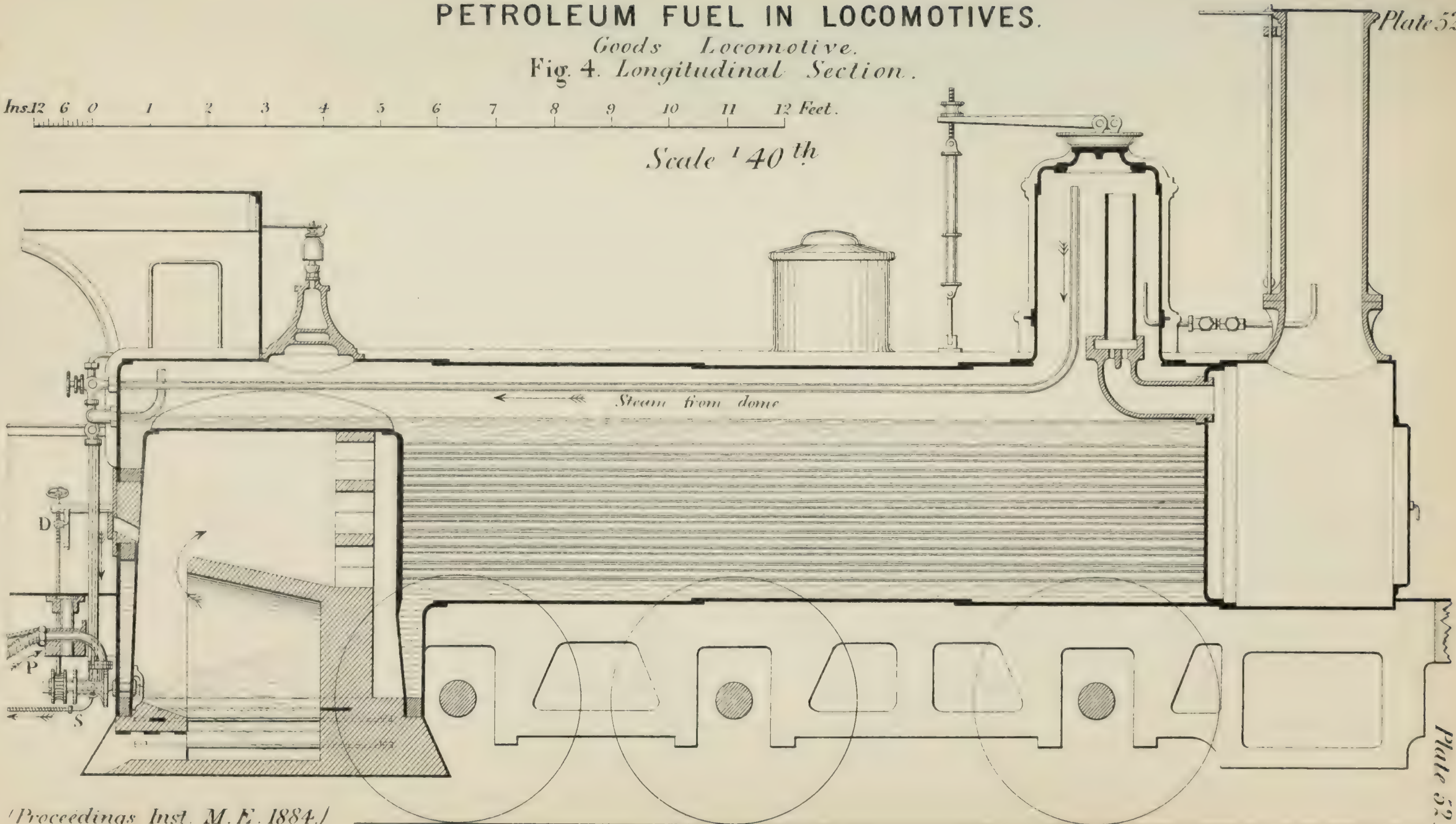
Scale 1/80th.

(Proceedings Inst. M.E. 1884.)

PETROLEUM FUEL IN LOCOMOTIVES.

Goods Locomotive.

Fig. 4. *Longitudinal Section.*



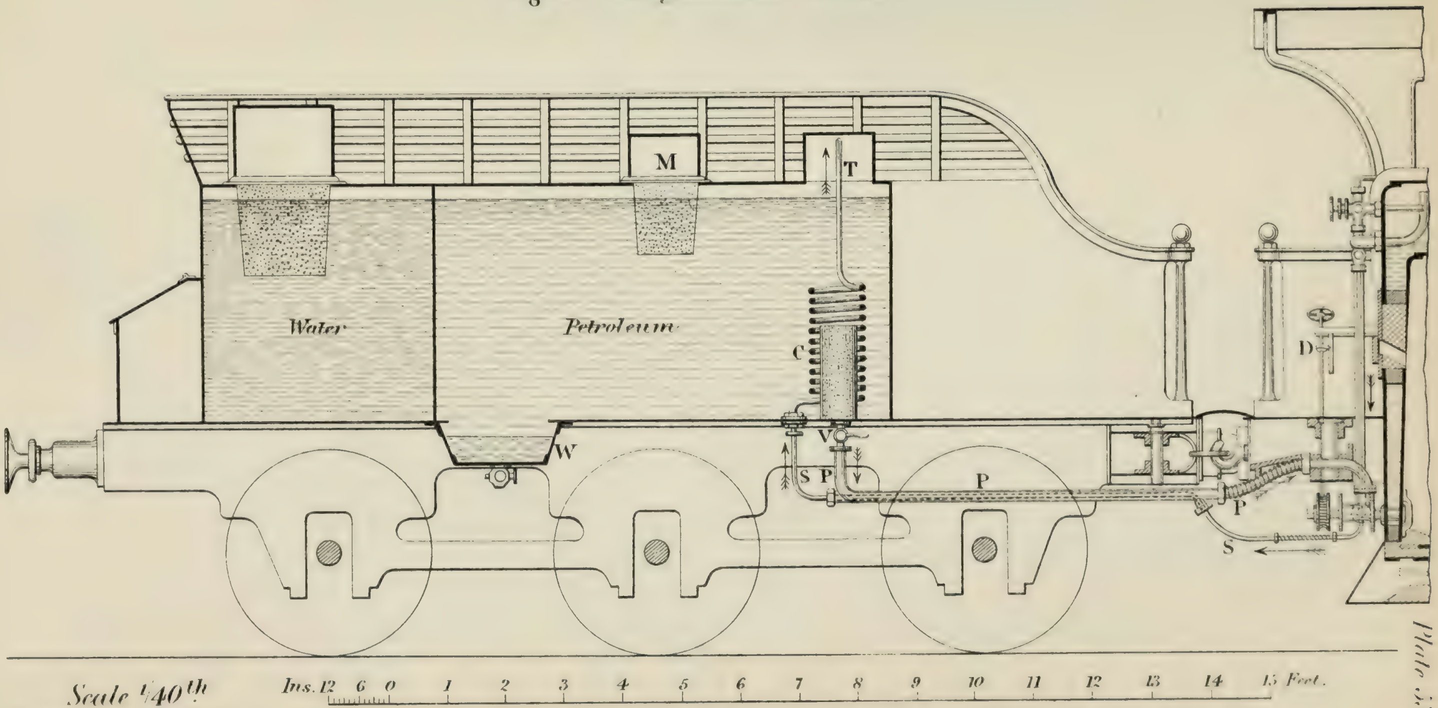
(Proceedings Inst. M.E. 1884.)

Plate 52.

PETROLEUM FUEL IN LOCOMOTIVES.

Goods Locomotive Tender.

Fig. 5. *Longitudinal Section.*



Scale 1/40th.

(Proceedings Inst. M. E. 1884.)

Plate 53.

PETROLEUM FUEL IN LOCOMOTIVES.

Combustion Chamber.

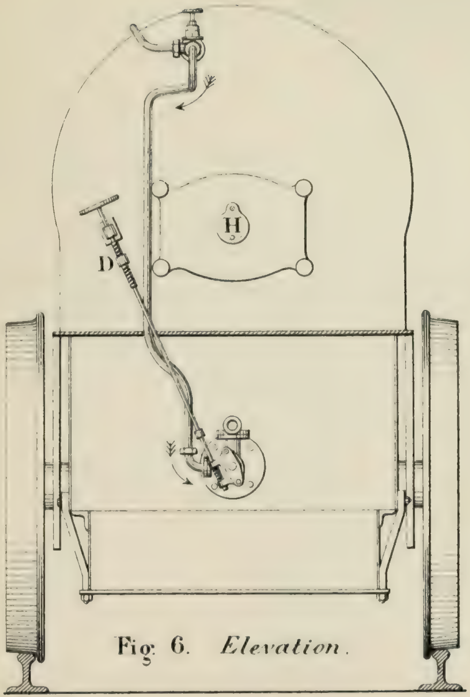


Fig. 6. *Elevation.*

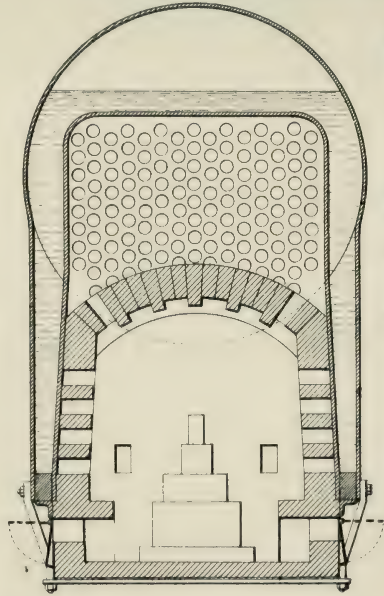


Fig. 7. *Transverse Section.*

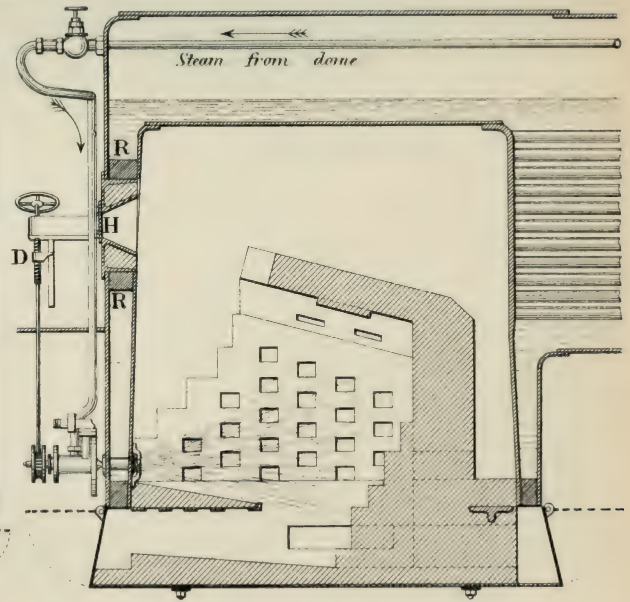


Fig. 8. *Longitudinal Section.*

Plate 54.

(*Proceedings Inst. M. E. 1884.*) *Scale 1/30th.* Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

PETROLEUM FUEL IN LOCOMOTIVES.

Combustion Chamber.

Fig. 9. *Transverse Section.*

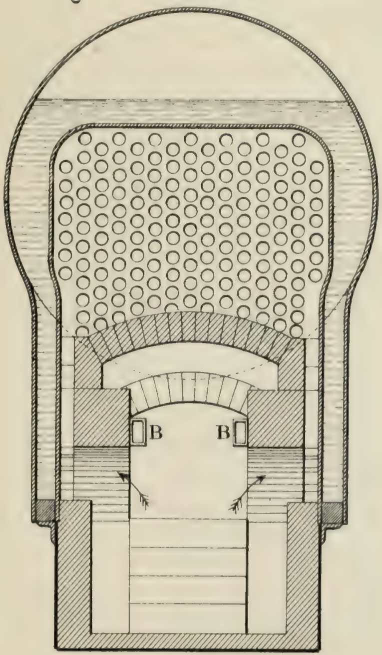
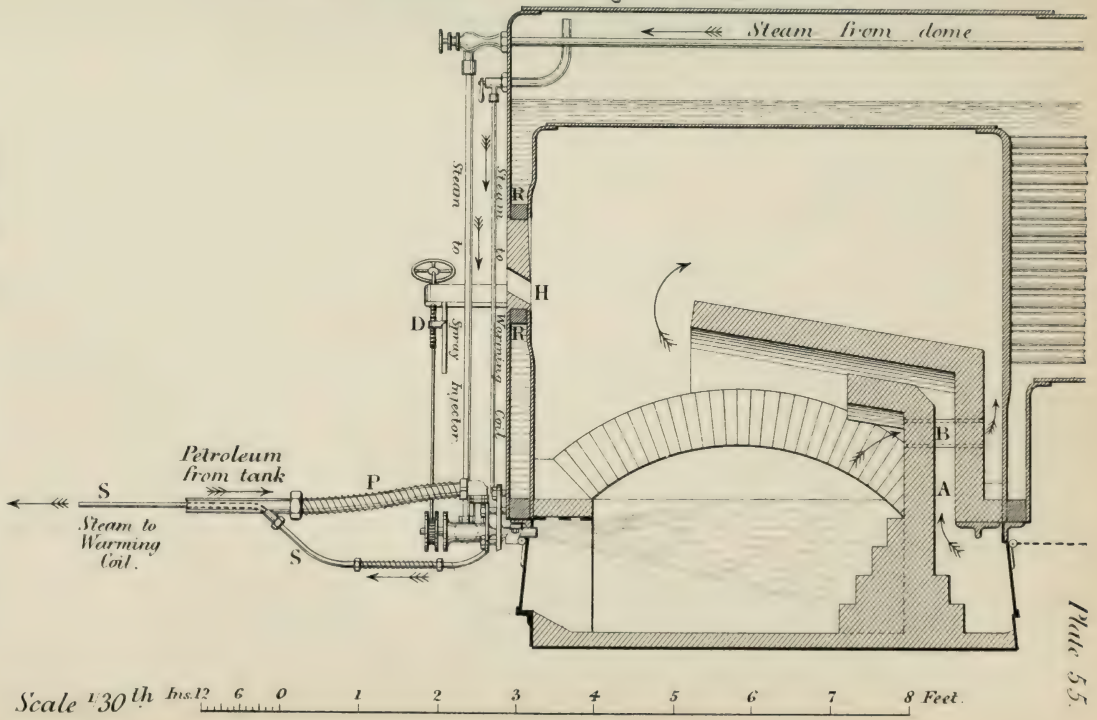


Fig. 10. *Longitudinal Section.*



(Proceedings Inst. M. E. 1884.)

PETROLEUM FUEL IN LOCOMOTIVES.

Galloway Boiler.

Fig. 13. *Longitudinal Section*

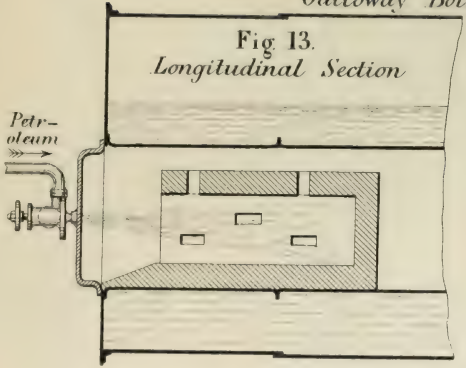
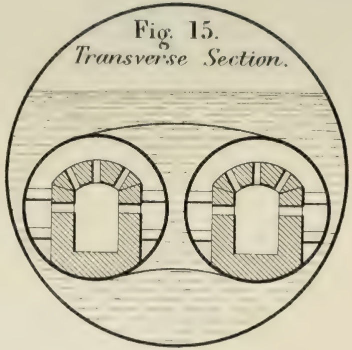


Fig. 15. *Transverse Section.*



Locomotive Combustion Chambers.

Fig. 11. *Plan of Fig. 8.*

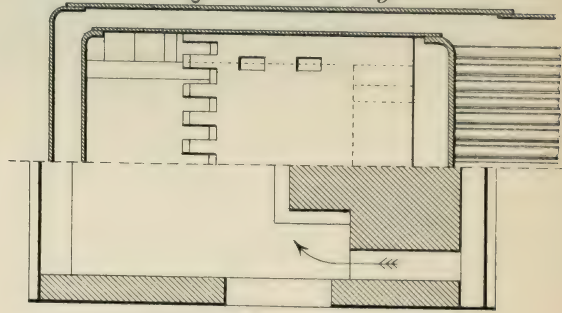
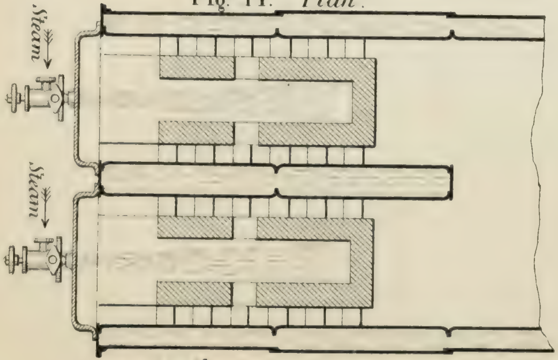


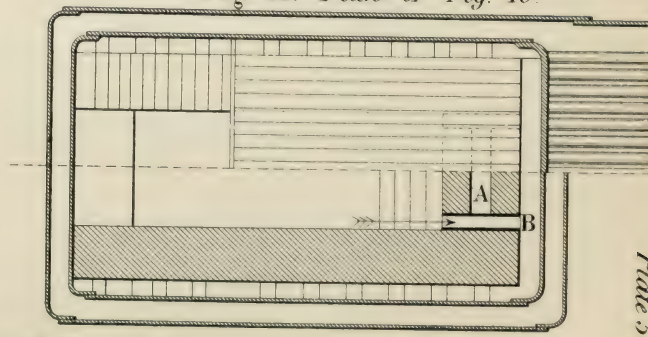
Fig. 14. *Plan.*



Scale 1/48th 0 1 2 3 4 5 Feet.

(Proceedings Inst. M. E. 1884.)

Fig. 12. *Plan of Fig. 10*



Scale 1/30th 0 1 2 3 4 5 Feet

Fig. 16. *Plan of Spray Injector.*

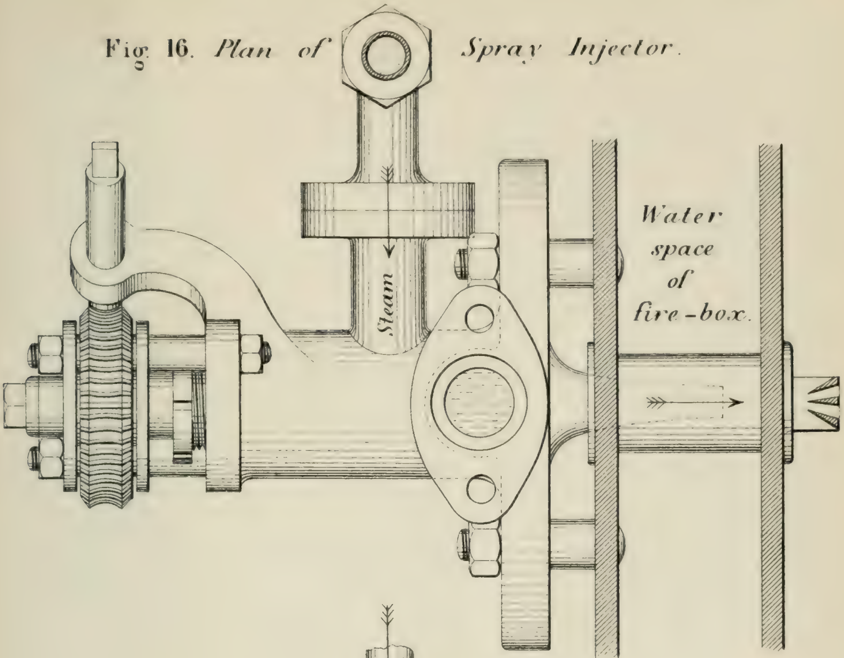
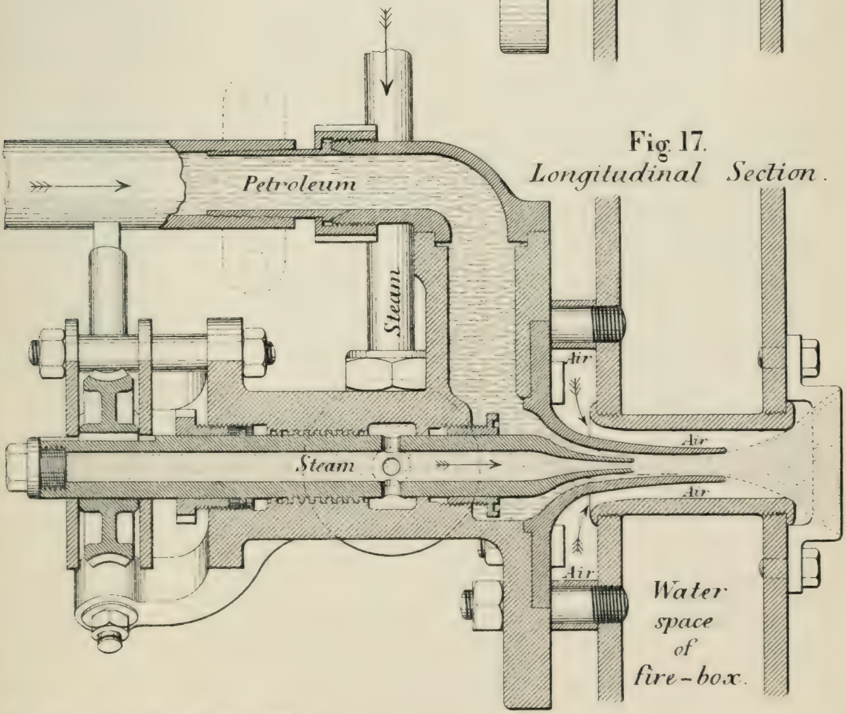


Fig. 17.
Longitudinal Section.



(Proceedings Inst. M. E. 1884.)

Scale 1/4th. 0 1 2 3 4 5 6 7 8 9 10 11 12 *Ins.*

PETROLEUM FUEL IN LOCOMOTIVES.

Distributing Tank.

Fig. 18. *Elevation.*

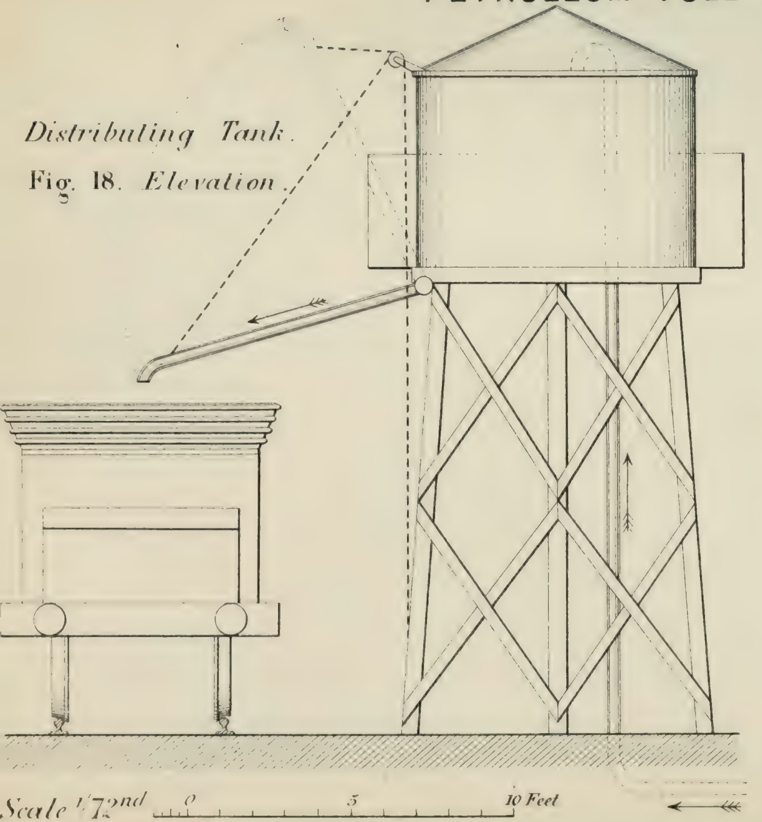
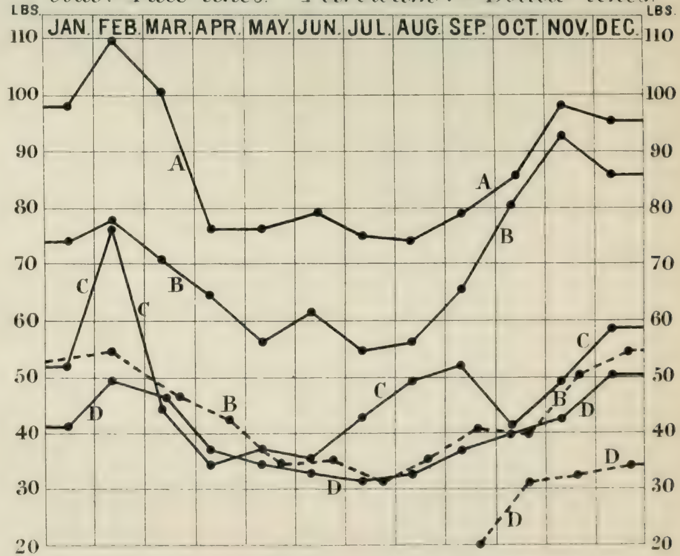


Fig. 19. *(See Table VI.)*

Consumption of Fuel per Train - Mile.

Coal:- Full lines. Petroleum:- Dotted lines.



A *Goods Engine,* 8 *wheels coupled, Goods Train.*
BB „ „ 6 „ „ „ „
C *Mixed* „ 4 „ „ *Mixed* „
DD „ „ 4 „ „ *Passenger* „

(Proceedings Inst. M. E. 1884.)

PETROLEUM FUEL IN LOCOMOTIVES. *Plate 59.*

Fire for heating Tyres.

Fig. 20. *Section.*

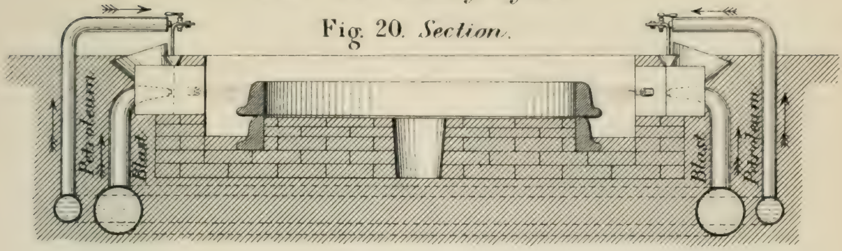
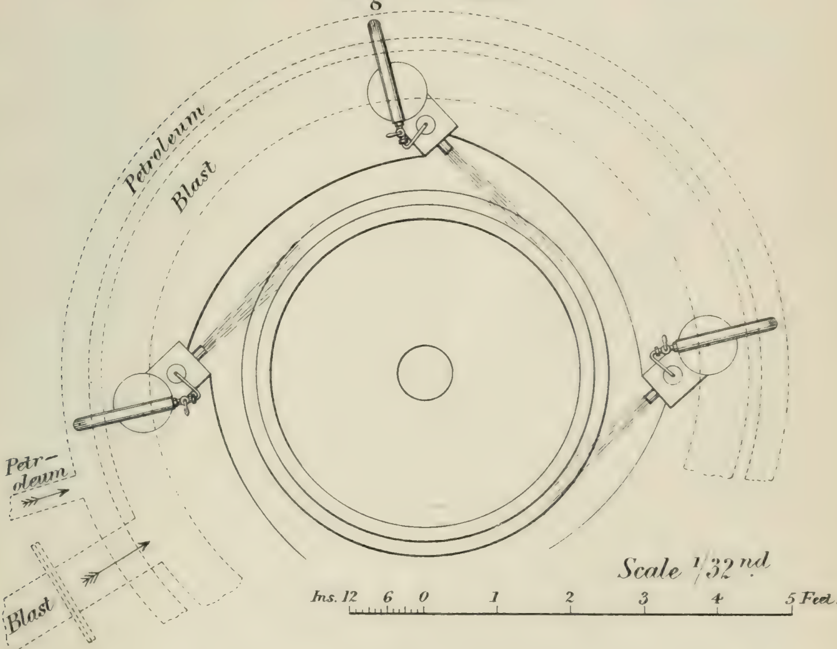


Fig. 21. *Plan.*



Scale 1/32nd.

Fig. 22. *Longitudinal Section.*

Spray Injector.

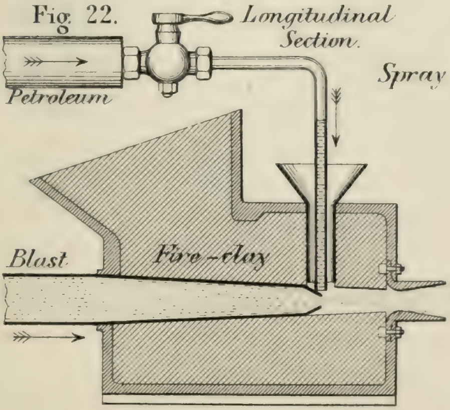
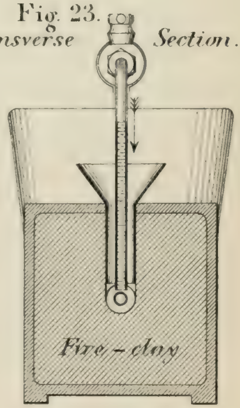


Fig. 23. *Transverse Section.*



Scale 1/8th. 0 5 10 15 20 Ins.

(Proceedings Inst. M.E. 1884.)

PETROLEUM FUEL.

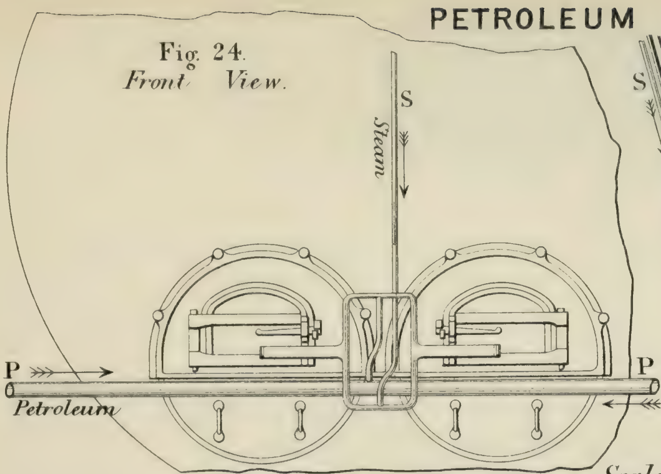


Fig. 24.
Front View.

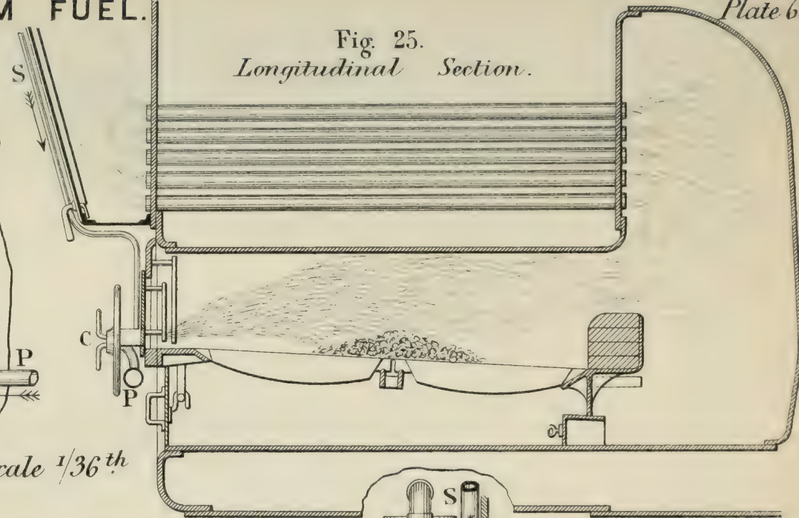


Fig. 25.
Longitudinal Section.

Scale 1/36th.

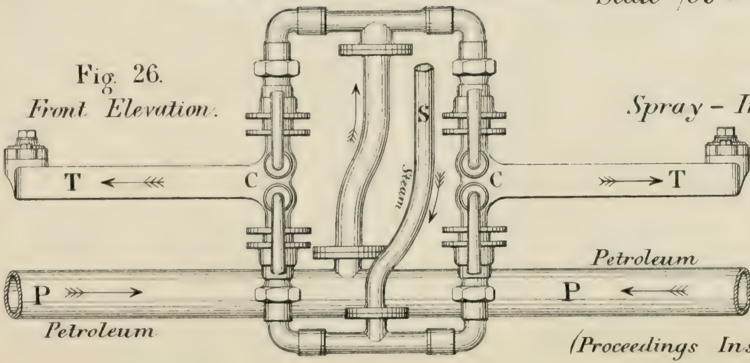


Fig. 26.
Front Elevation.

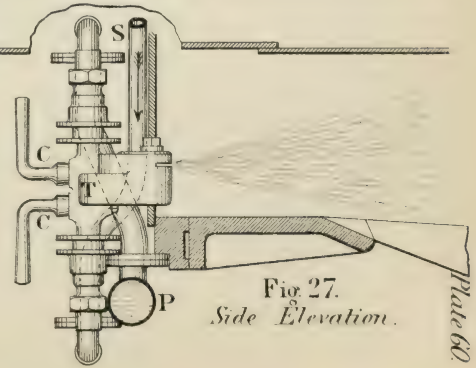


Fig. 27.
Side Elevation.

Spray-Injector.

Scale 1/12th.

(Proceedings Inst. M. E. 1884.)

MARINE BOILER CORROSION.

Fig. 1.

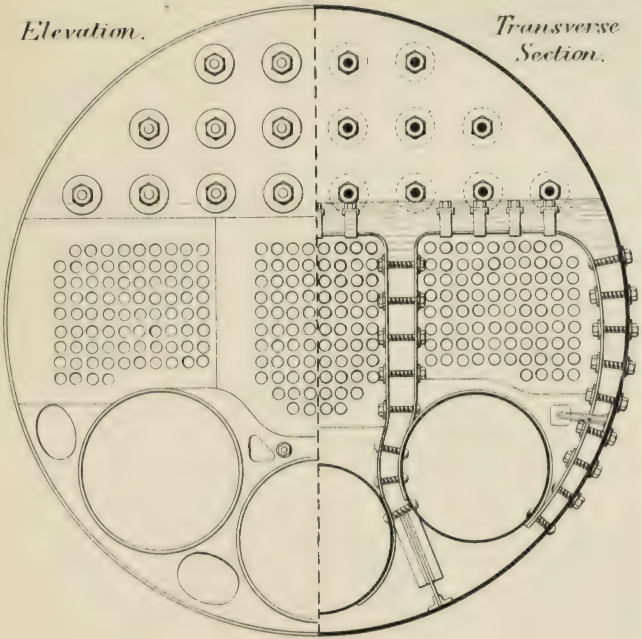


Fig. 2. Longitudinal Section.

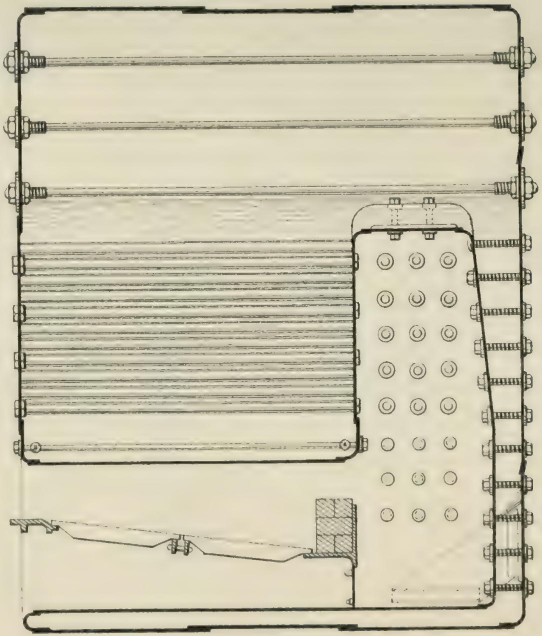


Fig. 3.

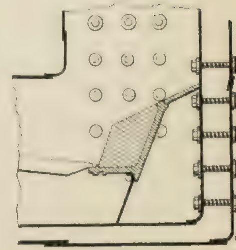


Plate 61.

Scale 1/48th

Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

(Proceedings Inst. M. E. 1884.)

MARINE BOILER CORROSION.

Fig. 4.

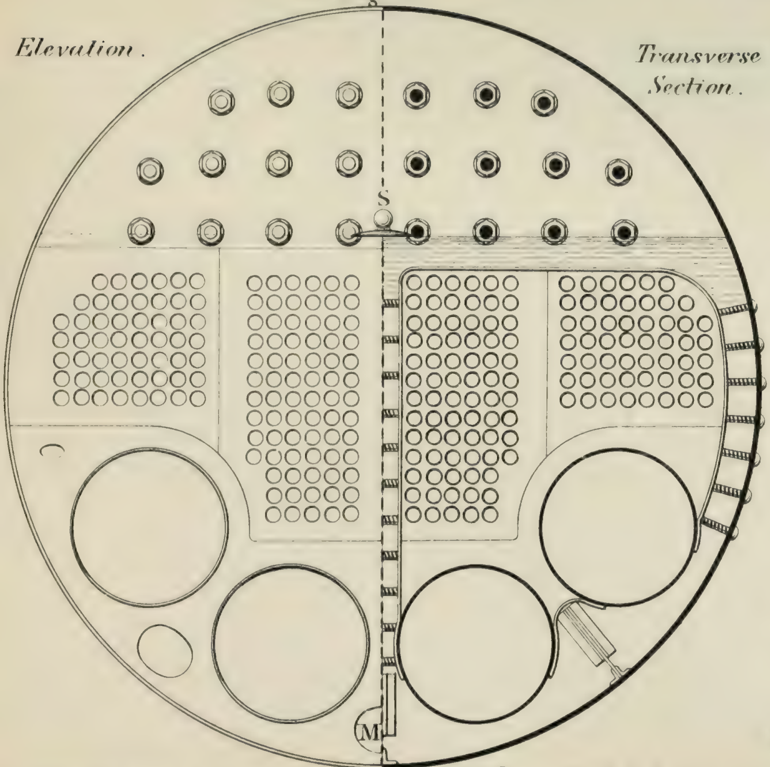
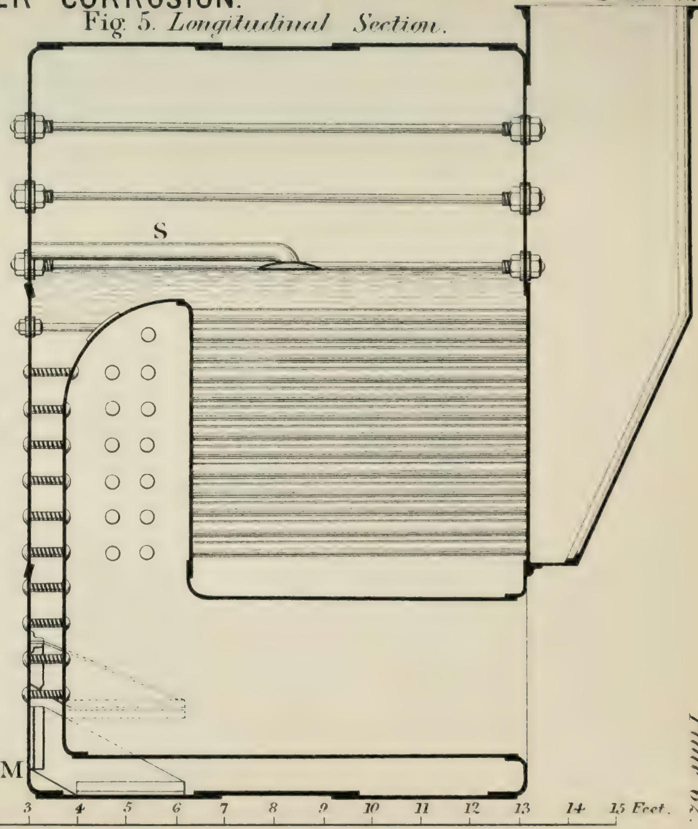


Fig 5. Longitudinal Section.



(Proceedings Inst. M. E. 1884.)

Scale 1/48th.

Plate 62.

Institution of Mechanical Engineers.

PROCEEDINGS.

November 1884.

The Autumn Meeting of the Institution was held in the Lecture Theatre, University College, Nottingham, on Wednesday, 5th November 1884, at Four o'clock p.m.; Charles Cochrane, Esq., Vice-President, in the chair, in the absence through illness of the President, I. Lowthian Bell, Esq., F.R.S.

The Chairman regretted to have to announce to the Meeting the renewed illness of the President, who was thereby prevented from filling the chair on this occasion; and he had himself been suddenly called upon to take Mr. Bell's place in consequence.

He had the pleasure of introducing to the Members present the Mayor of Nottingham, John Manning, Esq., who had very kindly attended for the purpose of welcoming the Institution to the town.

The Mayor said he had great pleasure in attending on the present occasion, with the Borough Engineer, Mr. Tarbotton, to offer a welcome to the Members of the Institution in connection with their Meeting in Nottingham. He shared the regret which was felt by all at the lamented illness of the President, whom he had hoped to receive as his guest on this occasion, and so to renew the friendship of former years. In his unavoidable absence however there was no doubt that under the chairmanship of Mr. Cochrane the present Meeting would be an agreeable and profitable one; and he could assure the Members that they had the cordial wishes of the town of Nottingham for the success of the Institution.

The Chairman thanked the Mayor for the kind welcome he had extended to the Institution. He was quite sure the Members would be pleased with their visit to Nottingham, judging from the way in which they were now received by the Mayor, and from the opportunities which were offered them of seeing in the town and neighbourhood what would be of most interest to them as mechanical engineers.

The Minutes of the previous Meeting were read, approved, and signed by the Chairman.

The Chairman announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following forty-one candidates were found to be duly elected:—

MEMBERS.

Reynold Henry Newton Alleyne,	Leeds.
Harry John Almond,	Newcastle-on-Tyne.
Samuel Anderson,	Westbury.
Lala Balmokand,	Lahore.
Archibald Barr,	Leeds.
Joseph Henry Bullock,	Walsall.
George Albert Bunting,	Huelva, Spain.
Charles Eastwood,	Liverpool.
John Etherington,	London.
John Slater Foster,	Birmingham.
Lala Ganga Ram,	Amritsar.
Henry Good,	Shanghai.
Robert Hudson,	Leeds.
Alfred Jenkins,	Abergavenny.
Felix Jones,	Birmingham.
Thomas Edward Kershaw,	Nuneaton.
Luke Longbottom,	Stoke-on-Trent.
Arthur Lowcock,	Shrewsbury.
Samuel MacCarthy,	Leeds.

Henry Coathupe Mais, ...	Adelaide.
George Massey, ...	London.
Hiram Stevens Maxim, ...	London.
Walter Maplesden Noakes, . . .	Sydney.
Stanley Faber Prest, ...	Barrow-in-Furness.
Lewis Richards, ...	Dowlais.
James Charlton Soulsby, . . .	Swansea.
Frederic Barry Stanton, . . .	Oldbury.
Albert Harrison Turner, . . .	Gold Coast.
William Wilkinson, ...	Wigan.
William Woodward, ...	Nottingham.
Charles Smith Worssam, . . .	London.

ASSOCIATES.

Edward Jackson, ...	Birmingham.
Richard Morgan Phillips, . . .	New York.
George Tilfourd, ...	Sheffield.

GRADUATES.

Hugh Myddleton Butler, . . .	Leeds.
Charles Philip King, ...	London.
René Lepan, ...	Lille.
William Philipson, ...	Newcastle-on-Tyne.
George Henry Sollory, . . .	Nottingham.
Edwin Arthur Slade Templeton, .	London.
Saku Yokoi, ...	Tokio, Japan.

The CHAIRMAN announced that the President, two Vice-Presidents, and five Members of Council, would go out of office at the ensuing Annual General Meeting, according to the Rules of the Institution; and that the list of those retiring was as follows:—

PRESIDENT.

I. LOWTHIAN BELL, F.R.S., ... Northallerton.

VICE-PRESIDENTS.

GEORGE B. RENNIE, ... London.
FRANCIS W. WEBB, ... Crewe.

MEMBERS OF COUNCIL.

WILLIAM ANDERSON,. . . . . London.
FRANCIS C. MARSHALL, ... Newcastle-on-Tyne.
E. WINDSOR RICHARDS,. . . . . Middlesbrough.
WILLIAM RICHARDSON, ... Oldham.
SIR BERNHARD SAMUELSON, BART., M.P., F.R.S., London.

Of the Retiring Officers, the President had unfortunately been compelled to announce his relinquishment of the presidency, in which his illness prevented him from continuing for a second year, as they would all have desired that he should do. On that point he had given a decided answer, stating that it was impossible for him to continue in office, inasmuch as his medical advisers had forbidden him to go on doing such an amount of work as he had hitherto been undertaking.

The following was accordingly the list of those retiring who had been nominated by the Council for re-election:—

VICE-PRESIDENT.

GEORGE B. RENNIE, ... London.

MEMBERS OF COUNCIL.

WILLIAM ANDERSON, ... London.
FRANCIS C. MARSHALL,. . . . . Newcastle-on-Tyne.
E. WINDSOR RICHARDS,. . . . . Middlesbrough.
WILLIAM RICHARDSON, ... Oldham.

The following nominations had also been made by the Council for the election at the Annual General Meeting :—

PRESIDENT.

JEREMIAH HEAD,. . . . . . . Middlesbrough.

VICE-PRESIDENT.

DANIEL ADAMSON, ... Manchester.

Election as Member.	MEMBERS OF COUNCIL.	
1872.	BENJAMIN A. DOBSON, ...	Bolton.
1874.	TOM HURRY RICHES, ...	Cardiff.
1876.	HENRY SHIELD, ...	Liverpool.
1879.	SIR JAMES N. DOUGLASS, ...	London.
1879.	ALEXANDER B. W. KENNEDY, . .	London.
1882.	WILLIAM DENNY, F.R.S.E., . .	Dumbarton.

The CHAIRMAN reminded the Meeting that according to the Rules of the Institution any Member was now entitled to add to the list of candidates.

Mr. R. PRICE-WILLIAMS made the following nomination :—

MEMBER OF COUNCIL.

1860. E. HAMER CARBUTT, M.P., ... London.

Mr. JOHN ROBINSON considered it would scarcely be respectful to their President if they did not as an Institution express their condolence with him on the present unsatisfactory condition of his health, which had led him, unfortunately for them, to intimate his inability to accept the nomination that would otherwise have been unanimously made at this Meeting for securing his continuance in the presidency for a second year. He therefore moved—"That the condolence of the Meeting be conveyed to the President, together with the earnest hope that before long he may be restored to such health as will enable him to resume his most useful labours in the cause of science."

Mr. ARTHUR PAGET had great pleasure in seconding the resolution, which required no words for commending it to every Member of the Institution. He might mention that at the previous meeting of the Council Mr. Bell had received a unanimous nomination for re-election to the presidency; and if his health had permitted, that nomination he was sure would have been unanimously endorsed by all the Members of the Institution. The Members would all cordially join in the request that the Chairman should express on behalf of the meeting their great regret that Mr. Bell's health did not permit him to accept the nomination for re-election as President of the Institution.

The CHAIRMAN promised he would convey to the President the condolence of the meeting on the occasion of his serious illness, in the terms of the motion now unanimously passed.

The CHAIRMAN reminded the Meeting that, if any Member had any motion to propose at the Annual General Meeting, in reference to the Bye-Laws, notice must be given of it at the present Meeting.

Mr. JOHN ROBINSON gave notice that at the next Annual General Meeting he should propose the following motions:—

1st. That Bye-Law No. 20 be expunged, and the following words substituted for it:—"The Secretary of the Institution shall be "appointed, as and when a vacancy occurs, by the Council; and "shall be removable by them by a six months' notice from any day. "The Secretary shall give the same length of notice. The Secretary "shall devote the whole of his time to the work of the Institution, "and shall not engage in any other business or occupation except "such as shall be of a purely literary character."

2nd. That the following words be added to Bye-Law No. 31 after the word *procedure*:—"which it shall not be competent for any "member of the Council to divulge." And that the word "may" be inserted before the word *delegate*.

3rd. That the following words be added to Bye-Law No. 32 after the word *accountant* :—" who shall be appointed annually by " the Members at a General or a Special Meeting, at a remuneration " to be then fixed by the Members."

Mr. George D. Hughes gave notice that at the next Annual General Meeting he should propose the three following alterations in Form A in the appendix to the Bye-Laws :—

1st. Instead of the words *being of the required age* to substitute the words " being not under twenty-four years of age."

2nd. After the words *we the undersigned* to add the words " proposer and seconder."

3rd. After the words *from our personal knowledge* to add the words " and we the three signers from trustworthy information."

The following Papers were then read and discussed :—

On the Mineral Wagons of South Wales ; by Mr. Alfred Slater, of Gloucester.

On the application of Electro-Magnets to the working of Railway Signals and Points ; by Mr. Illius A. Timmis, of London.

The Chairman moved the following Votes of Thanks, which were carried by acclamation :—

To the Mayor of Nottingham, for his kindness in granting the use of the Lecture Theatre in University College for the occasion of this Meeting of the Institution.

To the Authorities of University College, for the facilities they have so obligingly afforded in connection with the Meeting.

To Sir James Oldknow, Mr. Tarbotton, Mr. Johnson, and the other gentlemen who have so kindly invited the Members to visit their Works on this occasion.

To Mr. George D. Hughes, for the active part he has so kindly taken upon himself in preparing the arrangements for the present Meeting.

The Meeting then terminated.

Both on the morning of the Meeting and on the following morning, the Members were invited to inspect the Engineering Workshops and the Museum and Libraries in connection with University College. On each day also the Corporation Gas and Water Works were visited, on the invitation of the engineer, Mr. M. Ogle Tarbotton; and the following Works on the invitation of the several Proprietors:—

Sir James Oldknow's Lace Works, Great Alfred Street.
Mr. James Carver's Lace-Machine Works, Alfred Street.
Messrs. G. R. Cowen and Co.'s Engineering Works, Brook Street.
Mr. William Hooton's Lace-Machine Works, Great Eastern Street.
Messrs. E. Reader and Sons' Lace-Curtain Machine Works, Cremorne Street.
Messrs. Turney Brothers' Leather Works, Trent Bridge.

On Thursday, 6th November, the Locomotive Works of the Midland Railway, Derby, were visited on the invitation of the locomotive superintendent, Mr. Samuel W. Johnson.

ON THE MINERAL WAGONS OF SOUTH WALES.

By Mr. ALFRED SLATER, of Gloucester.

It is about thirty years since a paper was read before this Institution concerning Mineral Wagons. During this period the changes that have been made are in the increased carrying capacity, and consequently in the strength and form of the details, rather than in the general design. Mineral wagons form such an important part of the railway system that it seems surprising they have not received more attention; the explanation probably is that they are almost invariably constructed of timber, and therefore appear to call for less consideration on the part of mechanical engineers, in regard either to their construction or to the machinery for producing them. Renewed interest however is now attaching to this subject, owing to the construction of iron vehicles for India and other places abroad, and also to the action of some of the English railway companies, who are again constructing carriages and wagons with iron and steel underframes, with a view to economy in the cost of maintenance.

In the present paper the author does not purpose making more than a passing reference to iron wagons or to those with iron underframes, but to treat of private owners' wagons more particularly; because in no other similar area in the kingdom are there so many wagons owned by the traders, as in the South Wales district.* In the Midland counties and in the North there have always been a considerable number of private owners; but they are becoming fewer, or are owning fewer wagons, in consequence of some of the northern railways having become the owners of most of the mineral wagons working upon their systems: a policy more recently adopted by the Midland Railway Co., who are largely buying up the wagons working upon their line.

* This paper was originally prepared for the Summer Meeting held in Cardiff, from which it was adjourned through want of time for reading it there.

In South Wales there are various types of wagons, the following being a list of the more important:—Coal wagons to carry 10, 8, 7, 6½, and 6 tons; Coke wagons to carry 8 tons; and Iron-Ore wagons and Rail wagons to carry 10 tons, the two last being usually combined. The Coal wagons, which are by far the most numerous, may be divided into two types, namely:—those built to pass the inspection of the Taff Vale Railway; and those intended to work upon the Great Western and other trunk lines.

The adoption of some kind of proportion between the paying load and the tare or dead weight of the wagons has had to give way before the still more important principle of making every part strong enough to stand the heavy strains of ordinary traffic, and

TABLE I.—*Proportion between Paying Load and Dead Weight.*

Taff Vale Railway Regulations.	Capacity of Coal Wagon. Cubic Feet.	Nominal Load. Tons.	Maximum Tare. Tons.	Paying Load per ton of tare. Tons.
29 Nov. 1867.	205 to 210	6	3·50	1·714
	240 to 245	8	3·75	2·133
	not named	10	4·00	2·500
			Average	2·116
5 Aug. 1875.	240 to 245	8	3·85	2·078
	300 to 305	10	4·90*	2·041
			Average	2·059
12 Nov. 1883.	254	8	4·30	1·860
	347	10	5·25†	1·905
			Average	1·883

* If with laminated springs at both ends, 0·20 ton extra.

† If with laminated springs at both ends, 0·25 ton extra.

the still more damaging strains encountered in shunting. In proof of the statement that the proportion between paying load and dead weight is not now regarded in the same light as formerly, the accompanying figures in Table I are taken from the Taff Vale Railway regulations, in which the maximum limit assigned for the tare or dead weight of the coal wagon was as here shown. It will be seen that the average proportion of paying load per ton of tare has been diminished from 2·116 tons in 1867 to 2·059 tons in 1875, and to 1·883 tons in 1883.

It will be observed that not only have the wagons increased in cubic capacity and in dead weight, but that 6-ton wagons have gone out of the list and 10-ton wagons have come in. It is true that 10-ton wagons are mentioned in the regulations of 1867; but no particulars for construction are given. Certain it is that a wagon to carry 10 tons of coal with a tare of only 4 tons would not be made of sufficient strength to stand the work required of it.

Table II on the next page gives the sizes generally adopted for the principal parts of coal wagons of different tonnages as now and as formerly built to work in the South Wales district. The sizes here given, and the explanatory remarks which follow, may be taken as representing general practice; it would be impossible to describe all the forms and sizes that are to be seen in the district. A comparison of columns 3 and 5 will show a considerable increase in the strength of the 8-ton wagon as built to work upon the Taff Vale Railway; while from the line of "capacity per ton" it will be observed that no fixed rule exists as to the space to be allowed per ton of coal to be carried.

Body.—There should be as few projections as possible inside the wagons, so as not to interfere with the rapid discharge of the coal. Angle-iron is frequently put on the top boards, and is a decided improvement, as it strengthens the body considerably, protects the top boards from injury, and adapts the wagon better for carrying pit-wood, which is of such a form and is so loaded as to strain the body very much. The sides and ends are usually of red deal, but spruce is sometimes used. Each side is connected with the

TABLE II.—*Principal Dimensions of Coal Wagons of different tonnages.*

Principal Parts of Coal Wagons.		10-ton Wagon as now made. Known as :—		8-ton Wagon as now made. Known as :—		8-ton Wagon of ten years ago.	6-ton Wagon of twenty years ago.
		Taff Vale type. 1	Great Western type. 2	Taff Vale type. 3	Great Western type. 4	Taff Vale type. 5	Welsh lines. 6
Sole-bars, oak . . .	ins.	12 × 5	12 × 5	12 × 5	12 × 5	11 × 4½	10 × 4
Headstocks, oak . .	ins.	12 × 5	12 × 5	12 × 5	12 × 5	11 × 4	10 × 4
Middle bearers, oak . .	ins.	12 × 5	12 × 5	12 × 5	12 × 5	11 × 4	10 × 4
Diagonals, oak . . .	ins.	11 × 3	11 × 3	11 × 3	9 × 4	7½ × 3	8 × 3
Longitudes, middle, oak .	ins.	11 × 3	11 × 3	9 × 3	6 × 4	8 × 2½	7 × 2½
„ end, oak . .	ins.	11 × 3	11 × 3	9 × 3	4 × 3	8 × 2½	4 × 2½
Sides and ends, deal . .	ins.	2½	2½ or 3	2½	2½ or 3	2¼	2¼
Floor, deal . . .	ins.	2½	2½	2½	2½	2½	2½
Body, inside length .	ft. ins.	14 6	14 6	10 9	14 0	10 4	9 10
„ „ width .	ft. ins.	6 10	6 10	6 10	6 10	6 8	6 5
„ „ depth .	ft. ins.	3 6	3 8	3 5½	3 1	3 9	3 1½
„ internal capacity	cub. ft.	347	363	254	295	258	197
„ capacity per ton.	cub. ft.	34·70	36·30	31·75	36·87	32·25	32·83
Bearing Springs, length	ft. ins.	3 3	3 3	3 3	3 3	3 0	3 0
„ „ width .	ins.	4	4	3½	3½	3	3
Wheel base . .	ft. ins.	8 3	8 3	6 5	8 3	5 3	5 3
Axles, length between centres of journals	ft. ins.	6 4	6 4	6 4	6 4	6 4	6 4
Axles, diameter through wheels . . .	ins.	5	5	5	5	4½	4½
Axles, diameter in centre .	ins.	4½	4½	4¼	4¼	4	4
Journals, length and diameter	ins.	8 × 3¾	8 × 3¾	7 × 3½	7 × 3½	6 × 3	6 × 3

frame by iron knees, of which there are two in the larger wagons and one in the smaller; the knees are $2\frac{1}{2} \times 1\frac{1}{2}$ inch, and the foot, about 15 or 18 ins. long, is bolted to the middle bearer. If there is an end door, a knee is attached to the headstock, and to this knee the end door is hinged at the top and fastened near the bottom. In the smaller and older wagons, instead of the knees inside there were simply straight iron stanchions $2\frac{1}{2} \times \frac{3}{4}$ inch, placed outside the body, and bolted to the side of the sole-bars. The sides and ends are connected together by an iron corner-plate $\frac{3}{16}$ inch thick, extending from top to bottom, and 7 ins. along each. To prevent the body from

swaying to and fro, two iron bars $2\frac{1}{2} \times \frac{3}{8}$ inch are bolted diagonally to each sole-bar and along the side-boards. The fast end is attached to the headstock by two upright stanchions of oak $5 \times 4\frac{1}{2}$ ins.; or angle-iron $2\frac{1}{2} \times 2\frac{1}{2}$ ins. is sometimes used.

Doors.—Every coal wagon, with but few exceptions, has an end door or tip for shipping, and a door in each side. Various methods of fastening the doors are adopted. The coal wagons used in the North of England have hopper-shaped bodies; that is, the sides and ends slope inwards towards the bottom, and the coal falls out of the bottom of the wagon into the ship; they thus differ materially from the wagons used in South Wales, although there are a few wagons in this district which are similarly constructed, for use at certain iron works.

Floor.—In some instances the floor is made of sheet-iron, which enables the coal to pass more quickly out of the wagon when being tipped; but unless of a good thickness, sheet-iron is not sufficiently stiff, and buckles up, cutting off the bolts intended to hold it down to the frame, and thus freeing itself and occasionally going into the ship along with the coal. Spruce $2\frac{1}{2}$ ins. thick is very generally employed; but oak $1\frac{1}{2}$ inch thick, being more durable than deal, has been used with advantage, and being hard it soon becomes almost as smooth as iron. Wood floors are best laid transversely to the length of the wagon, that is, at right angles to the sole-bars. If laid longitudinally they are apt to break away from the nails, and to shoot out with the coal when the wagon is being tipped.

Framing.—All private wagons in the South Wales district, with but few exceptions, are constructed with oak frames. Some fifteen years ago, the author's firm constructed a number of wagons with the sole-bars of $\mathtt{I}$ iron, $9\frac{1}{4}$ ins. deep by $3\frac{11}{16}$ ins. broad and $\frac{3}{8}$ inch thick in the web; these bars have still many years of life left in them, though the remainder of the frame, which was of oak, has had to be replaced. Before the demand for coal wagons became so great and the competition so keen, the underframes were constructed of English oak; but now the purchaser is often content to have

foreign oak. Indeed English oak could not always be procured in sufficient quantity to keep pace with the demand. The life of the wagon is not much reduced in consequence of this change, provided sound timber be used; for after all no timber can long stand the excessively rough work to which coal wagons are subjected, no other kind of rolling stock meeting with such rough usage.

Draw-Gear.—In former years the Taff Vale draw-gear was of what is known as the "flat" type. One end of the wagon being devoid of hook and chain, the draw-bar had its extremity flattened out in plan into an eye, as shown in Figs. 1 and 2, Plate 63, to which the draw-chain of the next wagon was coupled by an open link with a pin dropped vertically through the eye. In 1872 new wagons were constructed with ordinary coupling at one end, as at A in Fig. 5, and with a compound coupling at the other end, as shown at B in Fig. 5, for enabling them to be coupled either to the "flat" type or to the ordinary. But the present regulations of that and other railways require all wagons to be constructed with the ordinary hook and chain at each end, as shown at A in Fig. 5; and wagons fitted with other types of coupling are being altered. Side chains have also been dispensed with. Some of the other lines bringing coal down to the different docks had special couplings, one form of which is shown in Figs. 3 and 4. Under the Taff Vale present regulations the draw-bar pulls from the headstocks, which are connected by long tie-rods, and thus form a continuous draw-bar, as in Fig. 6, Plate 64; but the usual practice is to draw from the middle bearer, as shown in Fig. 7. Under this arrangement the strain on the middle bearer is very severe, for it has to stand both the brunt of the pulling and also the bulk of the weight of the load; it is therefore sometimes made 6 ins. thick in the 10-ton wagons. The spring placed upon the drawbar is frequently only a single ring of india-rubber, 1½ or 2 ins. thick, as shown in Fig. 7, Plate 64.

Buffers.—As regards the buffing arrangements, the underframes of mineral wagons are of three principal kinds; first, those with dead buffers at each end; second, those with spring buffers at

one end and dead buffers at the other; and third, those with spring buffers at each end. As a general rule private owners will not incur the expense of spring buffers, not even at one end, unless they are compelled to do so. Where adopted, the spring buffers are usually of the "outside" type, Fig. 9, Plate 65, formerly known as Brown's, the spring being contained within the casing of the buffer, and the whole situated outside the headstock of the underframe. They were usually if not always of cast iron, but this material is not suitable for the work; consequently wrought iron is now largely used, with considerable economy in the cost of maintenance; the spring is either of steel or of india-rubber. In a few instances the more costly system of laminated springs has been adopted for draw-bar and buffers, Figs. 8 and 23, Plates 64 and 68, placed sometimes just within the headstock, Fig. 23, and sometimes between the two cross-bearers, Fig. 8. The sole-bars are then made to project about 9 ins. beyond the ends of the wagons, for the purpose of receiving the chains at the coal tips, as shown in Fig. 8, Plate 64.

In the outside type of spring buffer it will be seen that the blow is not conveyed direct on to the sole-bar and thence to the adjoining wagon; for, as shown in Fig. 9, Plate 65, the headstock intervenes between the buffer and the sole-bar; this intercepting piece of timber is the wrong way of the grain, and is very rapidly pommelled to pieces by the concussions in buffing, aided by the reduced area of the sole-bar at the tenons. In order to obtain, at a comparatively small expense, a really direct transmission of the blow, the spring buffer shown in Fig. 10 has been introduced, in which it will be seen that the blow is received direct upon the end of the sole-bar, through the spring and base of the buffer; this form therefore has some advantages. The pin or bolt used for fastening the head of the ordinary outside buffer, Fig. 9, has proved a great source of injury to the headstock; for the hole made to receive the pin is a source of weakness, and leads to early damage to the headstock. To remedy this, and to facilitate repairs, the author introduced a wrought-iron buffer with a gib and cotter fastening, its present form being shown in Figs. 11 and 12, Plate 65. This

method of fastening renders it unnecessary to cut away the headstock; and, besides enabling sufficient draw or initial compression to be given to the spring, facilitates the changing of a broken spring. To describe all the buffers and springs in use would be beyond the limits of this paper.

Axle-guards.—These are invariably of the W pattern, Fig. 16, Plate 67, made of $3\frac{3}{4}$ ins. × $\frac{3}{4}$ inch iron for the legs, and $2\frac{1}{2}$ ins. × $\frac{3}{4}$ inch for the wings; on the smaller wagons the legs are sometimes made of 3 ins. × $\frac{3}{4}$ inch iron. The bottoms of the guards on the same side of the wagon are frequently connected to each other by iron rods R about $1\frac{1}{8}$ inch diameter. The guards are secured to the sole-bars by seven $\frac{3}{4}$-inch round bolts, or in some recent instances by square bolts.

Brakes.—The invariable practice now is to have two brake-blocks acting on the wheels on the same side of the wagon, as shown in Figs. 13 and 26, Plates 66 and 69. Wood has been generally used; but of late years cast iron is becoming more in favour, as wood blocks wear away very rapidly, and require to be continually adjusted to the wheels, besides getting frequently burnt away by the friction. The leverage given is about twelve to one.

Bearing Brasses.—The brasses of coal wagons have a bearing of about $1\frac{3}{4}$ inch of circumference. They usually wear short at the inner end for want of lubrication; and as a grease-hole is so near to that end, the author is of opinion that an explanation is to be found in the recent report of the Research Committee on Friction, where it is stated that the weight being greatest in the centre of a bearing, the oil will force itself out with a considerable pressure through a hole placed in the centre. When the wagon is loaded, the axle is always slightly bent, so that the greatest pressure comes just about the back hole, which would accordingly gather up the grease supplied by the front hole, in its passage to lubricate the full length of the journal. In further proof it may be stated that, when a wagon is lifted, the grease in the front hole of the

brass is found to be the natural colour, while that in the back hole is not only dirty but quite hard. The lubrication is effected by means of grease, that known as "yellow grease" being commonly employed. Oil, though said to be a cheaper lubricant, is not likely to replace grease, on account of the cost of changing so many thousands of axle-boxes.

Bearing Springs.—The bearing springs, though usually the same width and about the same length for the same type of wagon, are varied very much by the different makers in regard to the number and thickness of the plates, ranging from four plates of $\frac{5}{8}$ inch thickness, to sixteen plates of only $\frac{1}{4}$ inch thickness. They invariably have flat ends, and bear on shoes attached to the underside of the sole-bars. There are frequently bolts to hold the springs to the axle-boxes.

Wheels and Axles.—The tyres are usually of Bessemer steel, and are attached to the skeleton by rivets; Mansell's and other fastenings are also much used. The skeleton consists of eight double spokes 3 ins. to $3\frac{3}{4}$ ins. wide, and $\frac{3}{4}$ inch thick; the boss is usually of cast iron, but sometimes of wrought iron. The axles are sufficiently described in the tabulated statement of dimensions already given, Table II, page 418.

Coke Wagons.—These are usually made by simply adding a few bars of timber, called "coke rails," to the top of the 10-ton coal wagons, as shown in Figs. 13 to 15, Plate 66. They will then carry 8 or $8\frac{1}{2}$ tons of coke.

Iron-Ore and Rail Wagons.—The best form of iron-ore and rail wagons, which invariably carry 10 tons, is shown in Figs. 16 to 21, Plate 67, representing one belonging to the Rhymney Railway Co. The end flaps are of iron, and are let fall inwards upon the floor when it is desired to use the wagons for carrying long rails or bars. These wagons are fitted with spring buffers at each end, and with drawbar cradle and spring. As a rule private owners' ore wagons

also carry rails, and are constructed with underframes similar to those of the coal wagons, and with dead buffers at each end. In a few instances there are doors in the floors of these wagons, for enabling the ore to be rapidly and economically discharged.

Iron-framed Wagons.—Another distinct type of wagon, not the property of any private owner, is the iron-framed wagon to carry 9 tons, shown in Figs. 22 to 24, Plate 68, which is now being constructed by the Great Western Railway Co. for their own use, and which may be seen constantly working in South Wales. The plan of the underframe is shown in Fig. 23, together with the sections of sole-bar and headstock in Fig. 25. There can be no doubt that iron or steel is the proper material for wagons which are subjected to continual rough work. There are many iron wagons now running that were made in 1844 and will yet last many years, notwithstanding that they have undergone conversion from the broad to the narrow gauge. A number of 10-ton coal wagons with iron frames, Figs. 26 to 30, Plate 69, which the author believes to be the first coal wagons of the kind made for private owners in the South Wales district, have just been constructed by his firm for Locket's Merthyr Steam Coal Co. The body is of the ordinary kind, having side and end boards $2\frac{1}{2}$ ins. thick, with angle-iron capping, two side doors, and one end tip ; the floor, Figs. 29 and 30, is of elm $1\frac{1}{2}$ inch thick, resting on longitudinal deal bearers so arranged as to give a current of air through the space S between the top of the frame and the underside of the floor, in order to prevent decay. There are spring buffers at each end, as dead buffers would cause too much strain on the rivets of the iron frame. To prevent any jar or sudden shock, the buffers and drawbars are provided with special india-rubber springs, which require no metal stops. The general arrangement of the underframe is shown in Fig. 28, the following being the particulars of the iron used :—

2 Sole-bars and 2 Headstocks,	channel iron	$9 \times 3 \times \frac{3}{8}$	inches.
2 Cross bearers,	do. do.	$5 \times 2\frac{3}{4} \times \frac{3}{8}$	„
1 Middle bearer,	plate	$8 \times \frac{5}{16}$	„
2 Cover-plates to headstocks,	do.	$8 \times \frac{5}{16}$	„
4 Diagonals,	angle iron	$4 \times 3 \times \frac{1}{2}$	„

Size of Wagons.—A quarter of a century ago the wagons of the South Wales district, and indeed of all narrow-gauge lines, were chiefly constructed to carry 6 to 7 tons; there were also some 4 and 5-ton wagons, some of which are still at work; then followed 8 tons; and now the 10-ton wagons are the most popular. The change was brought about partly by the extensive introduction of larger coal-tips at the Cardiff and Penarth Docks, and partly because the larger wagons enabled the increased demand for coals to be complied with at but little extra cost for wagon hire. The following statement shows the percentage of different sized wagons constructed by the author's firm for this district during two decades, and during the last three years; no doubt the returns of other makers would show similar proportions:—

	1861–70.	1871–80.	1881–83.
6, 6½, 7, and 8-ton wagons	77	35	8
10-ton wagons	23	65	92
	100	100	100

In the earlier part of the first decade the 6 and 6½-ton wagons preponderated; but, as already indicated, they gradually gave way to 7 and 8 tons, and these again to 10-ton wagons.

The author thinks it probable that the preference for larger wagons will continue to grow, and that it will not be long before the mineral freighters will ask for coal wagons to carry 12 tons. Indeed he has seen returns of the present 10-ton wagon having occasionally carried up to 11¼ tons. The increase in the tare of the wagon would be comparatively small, as very few parts would require strengthening; whilst the larger the capacity of the wagon, the larger is the proportion of paying load to dead weight, as already shown in Table I, page 416.

Discussion.

Mr. T. Hurry Riches considered the subject of mineral wagons in South Wales had been so fully treated by the author of the paper, that it would now be all the more interesting to members like himself residing in South Wales to hear in the discussion a comparison with the wagons of other districts.

Mr. R. Price-Williams was glad to have the opportunity of expressing his own thanks to the author for his most interesting paper, a contribution to the Proceedings which as far as he was himself concerned was exceedingly opportune; as the life-value of rolling stock was a subject to which he was at present devoting a great deal of attention, and there was a great deal in the paper of interest to him in his pursuit of that enquiry. His only regret was that the paper did not proceed further; and he would venture to suggest whether the author would give the benefit of his large experience in relation to the life-value of the stock which he had described. Table I, showing the proportion between paying load and dead weight, was particularly instructive. It had reference to the rolling-stock of the Taff Vale Railway, which he happened to know very well, having been at one time connected with it; and he had been much struck with the results there shown, which seemed to point to the fact that the increased capacity had not been obtained without a considerable addition to the tare. There seemed to him to be an impropriety in including the earliest form of 6-ton wagon with the 8 and 10-ton wagons, for arriving at the average paying load given in that Table for the first period of 1867, inasmuch as that class of wagon had been practically discontinued, and did not appear at all in the two later periods. This disturbed the accuracy of the conclusion; he found that, instead of taking 2·116 as the average of paying load per ton of tare in the earliest period, it really would be, omitting the 6-ton wagon, as high as 2·316; and the decrease between 1867 and 1875, instead of being, as appeared from the author's figures, only 2·7 per cent., was really as much as 11·1 per cent. Omitting the 6-ton wagon altogether, it

would be observed that in the 8-ton wagon the maximum tare had increased from 3·75 up to 3·85 tons, or only 2·7 per cent. in the period between 1867 and 1875; whereas in the case of the 10-ton wagon it had increased in the same period from 4·00 up to 4·90 tons, or 22·5 per cent. Then taking the next period, from August 1875 to November 1883, the results were equally striking, showing an increase of 11·7 per cent. in the maximum tare of the 8-ton wagon, and of 7·1 per cent. in that of the 10-ton wagon. The cubic capacity, it would be observed, had remained almost stationary; in fact from 1867 to 1875 it was actually stationary for the 8-ton wagon. The increase in cubic capacity between 1875 and 1883 was only 4·7 per cent. in the case of the 8-ton wagon, whereas in the 10-ton wagon it was 14·7 per cent. But seeing that the maximum tare in the 10 ton wagon had in the meantime increased 22·5 per cent. between 1867 and 1875, and 7·1 per cent. between 1875 and 1883, the total average increase of tare in the sixteen years for the 8 and 10-ton wagons together being 23·2 per cent., while the paying load per ton of tare had decreased as much as 18·7 per cent., the conclusion he drew was that the increase in tare was legitimately obtained: in other words, that the rough usage which that large class of wagons had been subjected to had directed the attention of private owners as well as of railway companies to the fact that increased strength, even at a sacrifice of carrying capacity, was adding considerably to the life-value. As to the actual result of that increase of tare in adding to the life-value, there was no information in the paper; and he should therefore be glad if the author would give the benefit of his experience on that point. Stated in a tabular form corresponding with Table I in the paper, the percentages of respective decrease and increase in paying load and dead weight stood as follows (page 428):—

In regard to buffers also, he should be glad to know what the author's experience was as to the effect of spring buffers in adding to the life-value of rolling stock. In travelling to Nottingham he had noticed, in looking at the stock which he passed on the way, what a large proportion of the wagons—whether of private owners or of the railway company he did not know—had dead buffers. As an

(Mr. R. Price-Williams.)

Paying Load and Dead Weight.

Percentages of Decrease and Increase between 1867 *and* 1883.

Taff Vale Railway Regulations.	Capacity of Coal Wagon.		Nominal Load.	Maximum Tare.		Paying Load per ton of tare.	
	Mean. Cub. Ft.	Increase. Per cent.	Tons.	Tare. Tons.	Increase. Per cent.	Load. Tons.	Decrease. Per cent.
29 Nov. 1867.	207½		6	3·50		1·714	
	242½		8	3·75		2·133	
			10	4·00		2·500	
	Average			**3·87**		**2·316**	
5 Aug. 1875.	242½		8	3·85	2·7	2·078	2·6
	302½		10	4·90	22·5	2·041	18·4
	Average			**4·37**	**12·9**	**2·059**	**11·1**
12 Nov. 1883.	254	4·7	8	4·30	11·7	1·860	10·5
	347	14·7	10	5·25	7·1	1·905	6·6
	Average			**4·77**	**9·1**	**1·883**	**8·5**

Summary.

Increase in Cubic Capacity, from 1867 *to* 1883 :—

8-ton wagon . . . . . . 4·7 per cent.
10-ton wagon . . . . . . 14·7 „
Average of 8 and 10-ton wagons together . **9·7** „

Increase in Maximum Tare, from 1867 *to* 1883 :—

8-ton wagon . . . . . . 14·7 per cent.
10-ton wagon . . . . . . 31·2 „
Average of 8 and 10-ton wagons together . **23·2** „

Decrease in Paying Load per ton of tare, from 1867 *to* 1883 :—

8-ton wagon . . . . . . 12·8 per cent.
10-ton wagon . . . . . . 23·8 „
Average of 8 and 10-ton wagons together . **18·7** „

economical question he could not help thinking that, although spring buffers no doubt added considerably to the first cost, yet the increased cost was well worth incurring, adding as it did so largely to the life-value of the stock.

In drawing attention in the latter part of the paper to the iron-framed wagon, the author had stated as a fact that iron wagons had been in use from 1844; it might be expected therefore that some reliable data could be furnished as to what their cost had been. Everything seemed to point to the fact that, having regard to economy, the iron-framed wagon was the vehicle of the future. Having himself got out some interesting statistics in regard to the actual number of private and railway wagons in the kingdom, which showed the enormous amount of money invested in that class of rolling stock, he thought it behoved railway companies and private owners alike to consider carefully the best form of structure.

Allusion having been made at the end of the paper to a probable 12-ton wagon, he should be glad to learn from the author whether there must not be some limit in regard to increased weight. The increase from 8 to 10 tons did not give the additional capacity that might be expected, in proportion at all events to the tare weight. He submitted therefore that there must be a limit, and he thought that 12 tons was rather over the limit for convenience of using and handling the wagon. The difficulty of shunting and handling a 12-ton wagon was much increased; and he questioned whether a 12-ton wagon could be handled without horse-power or some such assistance. As the Midland Railway Company were the largest carriers of coal in the kingdom, he hoped to hear something of the valuable experience obtained on that line by the locomotive engineer, Mr. Johnson, who was present.

Mr. Samuel W. Johnson considered the iron-framed wagons were open to the objection that if they got much damaged in collisions there was much more difficulty in repairing them than in the case of timber wagons. In regard to carrying capacity, he considered 10 tons was as high as it was desirable to go. Mr. Clayton, the carriage and wagon superintendent of the Midland

(Mr. Samuel W. Johnson.)
Railway, was present, and could give some information on the subject of the paper.

Mr. T. G. Clayton said the lifetime of wagons, and the construction of wagons belonging to private owners and to railways, differed so much that many opinions might be entertained upon them. With regard to iron-framed or wood-framed wagons, he might mention that as far back as 1844 the Great Western Railway had a large number of their wagons built with iron frames. Having been himself engaged on that railway as carriage superintendent, his experience of the iron frames had been that they were both troublesome and expensive in maintenance. Certainly they possessed greater durability, inasmuch as they would not rot away so soon as timber; but they could not be repaired anywhere and everywhere like timber frames, and in being shunted they frequently got bent and buckled up and out of square. The result of that experience was that ultimately the Great Western Railway found it would be better to revert to the wood frames, which were accordingly adhered to for some years: until there had recently been a return to the iron-framed wagon—why he could hardly say. It would be necessary he thought for the railways to give the matter very serious attention before adopting so great a change, because it would involve an almost entire change in the class of workmen. Instead of the present wagon-repairers, it would be necessary to employ girder-makers and men used to dealing with angle-irons, plates, and so on.

With regard to the lifetime of railway wagons, that was a point which he believed had been pretty well ascertained within the last ten years. Their lifetime was not so long as had once been supposed. It had been imagined they would last twenty years; but it had now been found they did not last so long.

The adoption of spring buffers, either outside buffers or those with long laminated springs, had no doubt increased considerably the first cost of the wagons, but it had tended to preserve them. It was found on the principal railways that spring buffers saved a great deal in breakages of goods. On the Midland Railway long

laminated buffer springs were the only ones used, and these gave an easy stroke. There had been a great deal of opposition to the long buffer springs in wagons on account of the cost. Some years ago the relative cost had been worked out of the long laminated buffer springs and the outside buffers; and it had been ascertained that the outside buffers cost 10*s.* per annum per wagon to keep in repair, while the laminated buffer springs cost only 2*s.* 6*d.*

With regard to increasing the carrying capacity of railway wagons to 10 or 12 tons or more, he was of opinion that an 8-ton wagon was the most useful and convenient size for ordinary purposes, and cost less in repair. It was well known that only a small percentage of the goods wagons were daily loaded up to their full carrying capacity, the average load not exceeding one half; but coal or mineral wagons were generally loaded to their full carrying capacity. Not only in former years, but particularly in the last two and a half years, during which time the Midland Railway had purchased nearly 40,000 coal wagons from private owners, he had noticed that in proportion to their age the 10-ton wagons were in a much worse condition than the 8-ton wagons; whilst the oldest, and those that seemed to have stood their work best for the greatest number of years, were the old 6-ton wagons. This would go to show that a wagon containing so great a weight as 10 tons of coal, being shunted and knocked about as it necessarily must be amidst the rush of traffic on railways, did not stand so well as smaller wagons, and also cost more for repairs than was in proportion to its extra carrying capacity.

Mr. Thomas Ashbury observed that from Table I he found that under the Taff Vale Railway regulations the 10-ton wagon had as much as 23·8 per cent. less paying load per ton of tare in 1883 than in 1867. The cubic contents of the coal wagons in the South Wales district seemed to vary much. The same Table showed that in 1867 the capacity of the 8-ton wagon of the Taff Vale type was 30·625 cubic feet per ton, while in 1883 it was 31·75; and in 1875 the capacity of the 10-ton wagon was 30·50, while in 1883 it was 34·70 cubic feet per ton. In Table II the

(Mr. Thomas Ashbury.)
8-ton wagon of the Great Western type as now made had a capacity of 36·87 cubic feet per ton, being 16·12 per cent. more than the Taff Vale 8-ton wagon of 1883, and 20·88 per cent. more than the Taff Vale 10-ton wagon of 1875. Not only had the capacity of the wagons been increased in that district, but considerable variations in the tare or dead weight were recorded. Thus the tare of the Taff Vale 10-ton wagon was given as 4·00 tons in 1867, while in 1883 it was 5·25 tons, being an increase of 31·25 per cent. He would therefore enquire firstly, whether the decrease in the paying load was an advantage or otherwise to the wagon-owners or to the railways. Secondly, why the capacity and tare of the wagons had been increased; and whether as a consequence there was any profit to the owners, or whether the benefit, if any, was received by the railways. And thirdly, whether the hauling of wagons from and to the collieries with such an increased dead weight was proved to be conducive or otherwise to the economical working of the coal traffic upon the lines of the collieries and of the railway companies.

Mr. Robert Gordon mentioned that in visiting the United States this summer he had noticed that there also they had been increasing the capacity of their wagons, and they had done so in order to reduce the tare proportionately. They had wagons weighing 20,000 lbs., built to carry a burden of 60,000 lbs., but some of them carrying as much as 70,000 lbs. He possessed drawings of the wagons used by Mr. Ely of Altoona, on the Pennsylvania Railroad, which weighed 19,800 lbs. and carried 60,000 lbs.; and also of the wagons on the Union Pacific and some other lines in the United States. Such a large increase in capacity was unknown in this country; it had taken place only within the last few years, and in consequence of the severe competition between the lines; and there had not yet been time to show what was its influence on the life of the wagons. The cars which a few years ago were intended to carry only 10 tons now carried 20 tons (the American ton being 2000 lbs.), and none of them weighed more than 18,000 or 20,000 lbs. On the West Shore line they were marked to carry 50,000 lbs. with a dead weight of 25,000 lbs.; but he had learned that they often

carried 10,000 lbs. beyond their marked capacity. The change was entirely due to the introduction of steel rails instead of iron, and to the severe competition between the leading lines. For the narrow-gauge lines of the Union Pacific, of 3 ft. gauge, intended chiefly for ore traffic, he had seen in the workshops at Omaha cars weighing 20,000 lbs., which were in every respect of the same size, except in width, as for the 4 ft. $8\frac{1}{2}$ ins. gauge. They were all built of wood, on the old system of bogie-trucks.

Mr. George D. Hughes asked whether there was any reason why wagons of even a higher capacity than 12 tons should not be adopted upon the railways of South Wales. The paper appeared to him to show clearly that as the wagons had increased in carrying capacity they had carried a larger paying load in proportion to their dead weight, and so the cost of haulage had proportionally decreased. If it was only a question of strength of construction, he did not see why wagons might not be made, as it had already been stated they were now made in America, capable of carrying 20 tons. Looking at the statement furnished by the author on page 425, it appeared that progress in the direction of greater carrying capacity, although clearly indicated, had been very slow. From 1861 to 1883 the proportion of wagons from 6 to 8 tons had fallen from 77 down to 8 per cent., while that of 10-ton wagons had risen in the same period from 23 up to 92 per cent.; so that it had taken twenty years to prove what seemed to be the self-evident proposition explained in the paper. If wagons to carry even more than 12 tons were to be introduced into the South Wales district, he presumed that the permanent way would still be strong enough to carry the additional weight. If that was so, it seemed to him the proper course would be to increase the carrying capacity of the wagons still more.

Mr. Ralph H. Tweddell enquired as to the action of the india-rubber spring in the buffer represented in Figs. 11 and 12, Plate 65. He had only seen the actual piece of india-rubber in its separate form of a disc or slab, but not when put together inside its casing. The construction was evidently quite novel, and he should like to be further informed on this subject.

(Mr. Ralph H. Tweddell.)

With regard to the general construction of mineral wagons, apart from the views held by the users of wagons, there was another point from which to look at the matter, especially interesting to mechanical engineers: namely the means of simplifying the construction so as to reduce the cost of their manufacture. Amongst other suggestions which had been made with that view was one by Mr. McDonnell for using principally bent angle-iron or T iron in the construction of the frames. In some wagons so made for the North Eastern Railway, all corner angle-irons and riveted joints were dispensed with, by bending long angle-irons or T irons to the required shapes. If that were done in the iron underframe represented in Fig. 23, Plate 68, the diagonal or oblique thrust-bars there shown would be made all solid out of a single length, bent by hydraulic pressure and flattened up against the headstock of the wagon. This would avoid the numerous corner angle-irons and joint pieces that formed part of the trouble which he believed was feared in the event of collision. He could not see that in a collision iron would come off much worse than wood, even so far as repairs went; because when iron-framed wagons came into the repairing shop after a collision, all the old material could be used again; while there was usually not much left of a wood frame. The iron, though it might be temporarily bent, could nearly all be worked up again.

He should also like to ask the author, who had perhaps carried out the practice of economical construction as successfully as any one in the country, what his experience was as to the cost of an iron or steel underframe, in comparison with one built of timber in the ordinary form, taking as a basis the carrying capacity of the wagon; and also what was the relative dead-weight of a wagon constructed on the composite principle, with an iron underframe and a wooden top, as compared with one constructed wholly of timber.

Mr. Arthur Paget desired to supplement Mr. Tweddell's enquiry about the india-rubber buffer shown in Figs. 11 and 12, Plate 65, by asking whether the draw-bar spring shown in Fig. 29, Plate 69, was a modification of the same construction on a smaller scale, as appeared to be the case so far as he could judge from the drawing.

Mr. Jeremiah Head said that, with regard to the question of wood *versus* iron or steel for constructing railway wagons, it was scarcely necessary to argue before mechanical engineers that stronger constructions could be made of iron and steel than could be made of wood. Iron and steel had superseded wood in ships, in bridges, and even to some extent in large buildings; and he could not but think that they were destined with equal certainty in the long run to supersede wood in mineral wagons. As to collisions, the construction of rolling stock should not be regulated with a view to standing collisions: there ought not to be collisions. On the North Eastern Railway iron wagons of the hopper type for carrying ironstone were being almost exclusively adopted. They were on a special plan, very carefully thought out, and based he believed on a model made by Mr. Charles Wood of Middlesbrough, who had paid a good deal of attention to the subject. In their present form they were so made that the bottom doors could be opened by touching a catch at the sides, without anyone having to go under the wagon at all; by releasing the catch the whole load was shot through at once. Wherever applicable that was the plan which ought to be adopted for mineral wagons. The same material that had been used for ships might, he thought, be used for wagons, and on the same principle—namely a very mild soft steel. In the case of ships it was found that a mild soft steel would stand any amount of bumping and battering, without injury to the structure. Mineral wagons were no doubt exposed to a good deal of the same sort of usage; and therefore he thought the same material would supersede all others in the long run.

Another reason, which was perhaps rather more a commercial, social, or economic, than an engineering reason, was that there were very large quantities of timber now used for railway stock, and that it almost all came from abroad. The money paid for it went out of the country and maintained a large number of foreign workmen, while in this country numbers of workmen were idle who could supply the material if iron or steel were used. Not only so, but the railway companies, who had the control and ordering of the wagons, would, by encouraging the iron or steel trade, profit to a much larger extent

(Mr. Jeremiah Head.)
in carrying raw materials than they possibly could by buying foreign timber.

With regard to the use of springs, whether as bearing springs or for buffers or draw-bars, there could not be a question he thought as to the great advantage that was secured thereby. When it was remembered how large a proportion of wagons belonged to private owners, and how those private owners had severally their different fancies—some of them not caring to adopt springs at all, and others having springs put in at one end only—he could not help thinking that a time would arrive when all railway wagons, or at all events all those travelling on the main lines, would be owned by the railway companies, who had a greater interest than private owners in the general safety of the public; there was consequently a pressure on them which there was not on the private owners. Whenever the time did come when all the wagons travelling on the main lines were owned by railway companies, they would then be made uniform and first-class in every particular. There would be no discussion as to whether they should have springs or not, or whether they should be made at a low or at a high cost. It would well pay the railways, having regard to the general public safety, and to the wear and tear of their main lines, and to many other considerations that did not affect private owners, to make the wagons as good as they could be made; and that would also be for the benefit of the travelling public.

In reference to the use of oil in the bearings, the members all knew and appreciated the valuable experiments which had been made for the Research Committee of the Institution by Mr. Beauchamp Tower; and in the wagon bearings described in the present paper the author had suggested that possibly the grease got squeezed out sometimes, to the detriment of the bearing brass and the axle, somewhat in the way in which the oil had been found to be squeezed out in the Research Committee's experiments. In those experiments however he wished to point out that there had been merely an absolute dead load, like an axle-box loaded with a heavy weight, upon a shaft running at a certain velocity. It was under those circumstances that the oil was squeezed out up the syphon, when it

was fed from the top; and even if fed from the bottom it was carried round, and he understood was squeezed up through the hole at top. But there was an important difference in the case of railway axles, namely the vibration under which they worked; and except for that constant vibration of railway axles he wondered how they ever kept lubricated at all. He believed therefore that what the Research Committee had ascertained in their experiments scarcely applied to the case of railway axles. The vibration was sufficient in railway axles to let the oil or grease get round, and to keep them well lubricated, in a way which could not be done in the research experiments.

Mr. Alfred Slater, in replying to the discussion, explained that he had included the 6-ton wagons in the earliest average tare given in Table I, simply because those smaller wagons formed part of the subject of the Taff Vale Railway regulations in 1867; and he had taken the three kinds of wagon as they then stood, and their maximum tares. It was true that the 6-ton wagons had afterwards disappeared, and it might almost be said in regard to the earliest statement also that the 10-ton wagons did not then exist; although they were named in the regulations of 1867, there were at that time very few of them.

As to the life-value of wagons constructed with light and with heavy tares, for his own part he certainly preferred a heavy tare for wear. Of course the wagons with heavier tare would cost more in the first instance; but if there was plenty of strength, there would be a saving in their maintenance. Without increasing the tare, increased strength could be got by using a different class of material, such as girder iron, instead of oak sole-bars. This was the case with the iron-framed wagon shown in Plate 69, which he hoped would stand its work at least as well as the ordinary oak-framed wagon to carry 10 tons; in fact his opinion was that the iron-framed wagon would stand its work better. It weighed 2 or 3 cwts. less than the corresponding 10-ton wagon built of timber.

He agreed with Mr. Price-Williams that iron under-frames would be the construction of the future; they were already being

(Mr. Alfred Slater.)
adopted in all countries except England, and manufacturers in this country had the pleasure of making them for foreign parts, but very seldom for use on English lines. Iron under-frames had no doubt given some trouble in the past; and Mr. Clayton had mentioned having experienced some trouble with those constructed by the Great Western Railway as far back as forty years ago. Possibly there had been some points about the design of the wagons at that time which would not now be adopted with present experience; but another point was the manner of putting the frames together. It should be borne in mind that at that time hand-riveting was almost exclusively used; but during the last few years there had been the advantage of hydraulic riveting, and in his opinion every rivet ought to be put in by hydraulic pressure, and not a single hand-rivet used. That had been his own endeavour in designing the frame shown in Fig. 28, Plate 69, in which every rivet, with one or two exceptions, could be got at by the hydraulic riveters used at his works.

The arrangement of framing adopted by Mr. McDonnell, to which Mr. Tweddell had referred, was no doubt a very good one, and would make a strong frame; but it was probably too expensive for wagons for private owners, as it would entail the employment of good angle-iron smiths; whereas in the iron frame shown in Plate 69 there was no smith's work on the girder bars or the angle-irons. This frame might be said to cost about £4 more than a similar frame of English oak; the other parts of the wagon would not be varied in cost. Mr. Tweddell's remark, that the bars of an iron frame if damaged could be worked up again, was quite correct, or nearly so. Some of the wagons named on page 419 of the paper as having been constructed with iron sole-bars had been in collisions and wild runs, and the sole-bars had rarely been damaged; but those that had been injured had been straightened, and with one or two exceptions used again in the wagon; even if unfit for wagon work they had been put to some other useful purpose. Two very recent collisions had just come to his knowledge, in which both iron-framed and wood-framed wagons were concerned. In the one case two of the iron-framed wagons met with no damage whatever beyond a few scratches and a broken buffer-plunger, whilst of the wood-framed

wagons one required two new sole-bars &c., another required one new sole-bar &c., and a third required rebuilding; a fourth and fifth were but slightly damaged. In the other case the one iron-framed wagon received a blow in the middle of the headstock, bending it inwards $2\frac{1}{2}$ inches; this wagon carried its load to its destination, and was then, though quite safe to work, sent in to have the iron headstock straightened. The leading wagon of the train of seven loaded wagons, all constructed of timber, which came into collision with this, was so badly damaged that it required to be nearly rebuilt.

As to whether an increase in the carrying capacity of the wagons would necessarily increase the tare, no doubt that result would naturally follow; and some difficulty might be expected to arise at any collieries where it was considered advisable, or where it was now the practice, to move wagons about either by hand or by horses alone. But in his own visits to collieries he noticed that the colliery owners were now becoming more or less possessed of steam power, —colliery locomotives; therefore he thought the question of the dead-weight of the wagons to be moved in shunting them about under the coal screens and elsewhere would not arise, and would give way to the progress which was taking place.

In regard to collisions, he agreed with Mr. Head that wagons ought not to be designed with a view to standing collisions; otherwise he was afraid they would have to be made even stronger than locomotives. Railway wagons should be built strong enough to carry traffic in the usual way; and in the event of collision, if the damaged wagons could go into such shops as those possessed by the principal railways or by the large wagon companies, he thought they would be better repaired than by letting the ordinary wagon-repairer cobble at them in the way that had now to be permitted in order to carry on the traffic. There was an advantage in iron frames in case of collisions. According to his own experience of the damage that was sustained in slight collisions, it was generally stated that it arose because the timber was somewhat defective from dry rot, or wet rot, or some other kind of decay. Although he had not as yet had much experience of damage done to iron frames, he did

2 P

(Mr. Alfred Slater.)
not think that these would be troubled with any decay of that nature.

The lifetime of wagons, as stated by Mr. Clayton, had undoubtedly been reduced during the last few years. The traffic was now carried much quicker than it was formerly. Wagons had now to run from South Wales to London or to Birkenhead in about half the time previously occupied. Wagon users complained very much if the wagons were more than a few hours on the journey.

Spring buffers undoubtedly increased the first cost; but there could be no doubt that they saved the wagons very much indeed. The difficulty still was, as it had been, and as it probably would remain for some little time, to get a spring buffer that would not become damaged in ordinary working. That had been the endeavour in the india-rubber buffer and draw-bar spring about which enquiry had been made, and in which one point was that as the spring was pressed homewards the resistance gradually increased, until the material of which the block was formed became a solid mass. The effect of the gradually increasing resistance was to take away the shock upon the wagon. There was also a reduction in the wear of the spring, because there was no friction of the india-rubber block against the sides of the casing. Those were two of the advantages of that spring; and if it carried out what was expected of it, he thought it would prove a success, and would be almost incapable of being damaged. The Midland Railway always had their wagons constructed with spring buffers, and he believed always used the laminated spring. There should be little doubt, he thought, that those who would go to the expense of the long laminated spring would find it the most economical; but when it did break it was very troublesome to deal with at an out station.

In reference to Mr. Clayton's concluding remark, he thought it probable that the 10-ton wagons being the more modern were not generally constructed of English oak, as already intimated in the paper (page 420). With proper construction and with proportionate draw buffer and bearing springs, the larger wagon would do its work correspondingly as well as the smaller.

With regard to Mr. Ashbury's question as to whether the change in the carrying capacity was for the benefit of the railways, the colliery owners, or the wagon owners, that was a pecuniary question which he thought hardly came within the scope of the paper. It was difficult to say exactly for whose benefit it would be. In the case of the railways the increased tare was a secondary consideration, if they could get a wagon that would carry two or three tons more coal.

In reply to Mr. Hughes' enquiry whether, having got as far as 10-ton wagons, the colliery owners in South Wales could not go further in the size of their wagons, there would probably be considerable difficulties in the way, on account of the tips at the docks, which would only take wagons of a limited height, width, and length, and also on account of the screens at the collieries, many of which would barely take the present 10-ton wagons. All those things would have to be altered if the wagons were increased in size. So too with the turntables and curves, not only at the collieries, but also at the shipping ports. For his part he thought there would be very little difficulty in constructing wagons to carry 12 tons, without interfering with either curves or turntables or tips or screens, if iron were used rather more extensively than it had hitherto been. With respect to the remark that it had taken twenty years to prove that the larger wagon was the better, it must not be overlooked that colliery owners whose sidings, turntables, screens, &c., were arranged for the smaller wagon, would naturally hesitate before incurring the expense of adapting them for the larger size; except for this, the change indicated by the figures given on page 425 of the paper would have shown itself more prominently in the earlier periods.

As to the carrying capacity being quite large enough at 10 tons, it had been stated by Mr. Gordon that in America wagons were now carrying 60,000 lbs. weight of goods, which at 2,000 lbs. to a ton would be 30 tons.

The Chairman remarked that it would be nearly 27 English tons of 2,240 lbs., the American lb. being the same as the English.

Mr. Slater said that was no doubt a large carrying capacity; and in his own experience such wagons had been constructed in England, to be sent out to South America for use in that country. There was no difficulty in constructing such wagons, if the builder was allowed as much room as was wanted for the wheel-base, or if they were bogie wagons like those running on the American lines. Under such circumstances a wagon could be constructed as large as might be required. But wagons to carry 27 tons of coal in this country could not be adopted unless the tips, screens, &c., were altered to suit them.

The question of railway companies owning all the wagons was of course one of policy rather than of engineering or construction; and there might be considerable diversity of opinion in regard to it.

With reference to Mr. Head's remark that the result ascertained by the Research Committee on Friction scarcely applied to railway axles, he would observe that he had been seeking for a reason why the back part of the journal did not get lubricated properly; and he was still of opinion that the squeezing of the grease into the back hole of the bearing brass was the cause of the deficient supply. In this view he was confirmed by experiments made by himself; and these experiments also proved the absolute necessity of vibration, to which Mr. Head had alluded.

The Chairman referred to the questions which had been asked as to the buffer shown in Figs. 11 and 12, Plate 65; and he enquired whether the appearance presented by the india-rubber spring was there correctly shown.

Mr. Slater replied that the appearance of the spring in section was correctly shown in Figs. 11 and 12, Plate 65. In its outer profile the india-rubber spring was conical or dome-shaped, while the inside was hollowed out into a kind of trumpet-mouth. For a draw-bar spring it was made with a large hole in the apex of the dome, for the draw-bar to pass through.

Mr. Arthur Paget said if he understood it rightly the spring seemed to act partly by the elasticity of the rubber, and also partly by that of the air compressed inside its hollow interior. If that was the case, it appeared to him that it might have one great advantage which was not possessed by ordinary springs, namely that while it would give a great and steady resistance to compression it would give a less active or sudden rebound than any other spring that he had seen; and he wished to ask the author if that was so. The construction appeared to him to be an entire novelty, and a most useful spring for the purpose.

Mr. Slater replied that Mr. Paget was quite right in his surmise. The spring gave great resisting power and a very slow rebound; there was therefore far less strain upon the buffer fastenings. It was well known that in the ordinary buffer, when fastened with a nut or bolt at the back, the sharp rebound of the steel spring sometimes broke off the bolt, and allowed the plunger to fall off on the line.

The Chairman desired to call attention to the question of the lifetime of wagons under varying conditions. It would be obvious that the lifetime of a wagon was not measured merely by the number of years that it lasted, if it was called upon to do double duty, as was now the case in comparison with former years. In considering the lifetime of a wagon therefore, it would be necessary to have some information as to what number of train-miles it had run, before any accurate opinion could be formed.

The Members he was sure had all been very much gratified with Mr. Slater's able paper and the discussion it had provoked, and would join in a hearty vote of thanks to the author.

ON THE APPLICATION OF ELECTRO-MAGNETS TO THE WORKING OF RAILWAY SIGNALS AND POINTS.

By Mr. ILLIUS A. TIMMIS, of London.

The object of the present paper is to describe a new, powerful, and economical Electro-Magnet, capable of exerting its pull in a manner suitable for convenient application to the mechanical working of Railway Signals and Points. Its main features are its great power, which is exerted through a long range, and is under perfect control; and its economy, both in exerting the initial pull which effects the mechanical movement required, and also in retaining the moving parts after the desired movement has been effected.

The rapid growth of railway systems and their consequent complexity have rendered urgent the application of electricity for the working of railway signals and points, and for checking the work done by signalmen and pointsmen. Though much has been accomplished in this direction both in this country and elsewhere, there has hitherto been always one initial want:—namely an electro-magnet, which, with a low average current and a small electromotive force, shall give a powerful, long, and well-balanced attractive pull. A range of pull of only half an inch, which has hitherto been the practical limit with electro-magnets, is evidently not long enough to be of use for heavy mechanical work, such as pulling signal-arms over or throwing machinery in and out of gear; and although the range can be increased by multiplying gear up to two or three inches, yet the increased current then required for making the attraction powerful enough at the initial half-inch distance is so enormous that two difficulties present themselves which are almost insuperable:—firstly the expense; and secondly the destructive violence of the final impact, in consequence of the attraction increasing inversely as the square of the distance of the armature from the magnet, and for part of the stroke inversely as the cube.

In the ordinary form of the electro-magnet, a core or bar of soft iron, wrapped round with a coil of wire or tape, and bent into the shape of a horse-shoe, attracts to its poles a plain armature; and by some natural law, as yet unsolved, the working pull of such a magnet practically ceases, as already stated, when a distance of only half an inch between the magnet and the armature is exceeded. In the electro-magnet of tubular form, thence called a *solenoid*, a hollow core or tubular bobbin of brass is wrapped round with wire or tape; and a central rod of soft iron, sliding lengthways inside it, forms the armature, which is drawn or sucked longitudinally into the core by the attraction of the bobbin coil, until it reaches a central position in relation to the magnetic field; in this position the attraction is symmetrical in all directions, and is therefore neutralised. Although a considerable length of attractive pull can be got with such a magnet, the current of electricity required to give any strong initial pull is so excessive that its cost is prohibitory; moreover it is clear that the holding power falls to zero when the armature reaches its central position longitudinally. In order to obtain adhesive power, or what is called a "retaining" pull, the internal sliding rod or armature is made shorter than the length of the hollow bobbin, and is capped at one end with a disc of soft iron, which, coming in contact with that end of the bobbin, thereby prevents the armature rod from reaching its central or neutral position within the bobbin, and leaves a corresponding reserve of holding power against the end of the bobbin.

Currie Long-Pull Magnet.—In the long-pull electro-magnet, shown in Fig. 1, Plate 70, which is the invention of Mr. Stanley Currie, the principle adopted is a combination of the horse-shoe magnet and solenoid, with additions; but the construction is so materially modified as to give far greater power and efficiency, and the magnetic attraction is more evenly distributed over a longer range, while the initial pull is stronger and acts at a greater distance than in any other electro-magnet of the same weight and with the same current. The range already attained in practice is $3\frac{1}{2}$ inches, and can be increased.

The bobbin B, here shown standing upright on one end, is made with a tubular core C of soft iron; and the coil of wire K wound around it is surrounded by an outer casing of soft iron B of the same weight as the core, with a soft-iron base plate P at the bottom of the bobbin, connecting the core with the outer casing; a brass plate V covers the bobbin at the top. The copper wire used in the coil is No. 18 Birmingham wire-gauge, or 0·048 inch thick. The armature consists of three portions, each one playing its part in the work to be done. The central stalk A of soft iron is rather shorter than its own range of motion; and is encased in a brass tube T, which is prolonged below it so as to form a guide, fitting within the bobbin core C. The soft-iron cap or disc D, fastened on the top of the central stalk A, is slightly larger in diameter than the outer casing of the bobbin B. It is made by preference of two or more thicknesses of flat plate, to assist in demagnetisation; but it must be thick enough to prevent saturation with any working current. Round the edge of the disc runs a cylindrical rim or flange F projecting downwards; it is so shaped as to suit the attraction required, and it comes within the range of attraction of the outer casing B of the bobbin when the lower end of the central stalk A has entered within the core C. When the rim in turn has done its duty, the disc D comes within range of attraction of both outer casing B and inner core C.

Uniformity of Pull.—So long as the central stalk or armature rod is altogether out of the bobbin core, the attraction upon it continues to be inversely as the square of its distance from the bobbin; but as soon as the lower end of the iron rod A enters within the orifice of the core C, the force of attraction becomes lost upon so much of its length as is inside the core. The same diminution in attractive force holds good in regard to the flanged rim F of the armature disc, as soon as its lower edge passes below the upper edge of the bobbin B. The force of attraction varies also directly as the mass of the body attracted. Advantage is therefore taken of these two principles in combination, to regulate or adjust the effective attraction in such a way as to obtain some sort of approximation towards uniformity of pull throughout the $3\frac{1}{2}$ inches range of stroke of the

armature. This is accomplished by tapering in the manner shown in Fig. 1, Plate 70, the lower end of the armature stalk A and also of the flanged rim F, according to the desired adjustment of the attractive force; in addition to which the thickness of the armature disc D and the distance that its flanged rim F projects downwards, as well as the thickness of the rim, can also be varied; and in some cases moreover, as in some of the examples shown in Figs. 4 to 14, Plate 71, the bottom edge of the flange is made of a serrated or wavy form, so as to prevent the pull from suddenly increasing as the disc nears the bobbin. The result is that, when the strength of the pull on the armature stalk and flanged rim is decreasing, owing to their having both of them reached and passed the position of maximum attraction, the pull on the disc is increasing as it nears the magnet head. In this way, and in combination with a counterweight acting at a suitably varying leverage, an approximately equal pull is obtained through a considerable range, and violence of contact in the closing of the disc upon the magnet is avoided. By suitably adjusting the several proportions of the various parts, the pull can be so greatly varied both in force and range that it can be adapted to meet almost any requirements.

Double Length of Pull.—A double length of pull is readily obtained by the simple tandem combination shown in Fig. 3, Plate 71. Here a pair of single magnets on the foregoing principle, arranged at a fixed distance apart, have their armature guide-rod A in common; the lower armature-disc L is made fast upon the rod, while the upper disc U bears down against a shoulder upon it. The range of the lower disc being nearly double that of the upper, the first half of the pull is given by the upper; and by the time the upper disc U has closed upon its own bobbin, it has brought the lower disc L within the attractive range of the lower magnet, by which the second half of the pull is then given, the armature rod A now sliding free through the upper disc U. This arrangement is suitable for working signal-arms that are required to stand at the three positions of danger, caution, and line clear, as shown in Fig. 3.

Railway Signals.—In the application of the electro-magnets to railway signals, the ordinary signal posts and arms are utilised; but it is advisable that the bearings and working parts should be made as true as practicable, because, though friction is not so material when the work is done by manual labour, it is of the utmost importance that it should be reduced to a minimum where electricity is the motive power. As there are no complicated parts, and the movements are all simple and direct, there is no difficulty on this point.

In Fig. 2, Plate 70, is shown the application of a single magnet to an ordinary signal-arm intended to stand in only the two positions of danger and line clear. The magnet M is fixed upright on a bracket at the back of the post, and a chain from its armature pulls upon a quadrant arc Q centred on a horizontal spindle above it. The quadrant carries a lever and counterweight W, acting in opposition to the pull of the magnet; and also an arm which is connected by a rod R with a bell-crank L centred at the side of the post. Another rod S connects the bell-crank L with the semaphore and spectacle. When the magnet is out of action, the semaphore is held up horizontally at danger by the weight of the spectacle, in conjunction with the counterweight W on the quadrant lever, which then comes against a stop. In this position all the parts are locked, in consequence of the quadrant arm being then on its dead centre; that is, the quadrant arm and bell-crank L are so arranged that the direction of the rod R connecting them passes then through the centre on which the quadrant Q turns. For yet greater security of locking, it is preferable indeed to let the connecting-rod R be even a trifle beyond the dead centre, so that any pull upon the bell-crank, from wind pressure or accumulation of snow on the semaphore, shall hold the counterweight lever W still more firmly against its stop. The locking is thus done mechanically, and is independent of the magnet. On bringing the magnet into action by a current from the signal box, the pull of the armature rotates the quadrant arc, raising the counterweight and spectacle, and lowering the semaphore, as shown by the dotted lines; in this position the semaphore is retained so long as the electric current is continued. On the cessation of the current, the semaphore is automatically

raised again to danger, and locked there mechanically without the use of extraneous catches, which is a most important feature.

In Fig. 3, Plate 71, is shown the application of the double magnet or tandem arrangement to a balanced semaphore centred at mid-length. Here the pair of magnets are fixed on one side of the post, and the quadrant arc on which they exert their pull is fixed on the spectacle spindle. A rod R connects the spectacle with a crank on the semaphore, and the weight of the spectacle brings the semaphore to the horizontal position of danger, in which it is locked mechanically as before, by the connecting-rod R being then on its dead centre. An electric current sent to the upper magnet pulls the semaphore to an angle of 45° for caution; and a second current sent to the lower magnet pulls it vertical for line clear. In either position, as shown by the dotted lines, it is held by the spectacle acting as a counterweight against the retaining pull of the magnet.

Electric Current.—Under ordinary circumstances a current of 3 ampères is amply sufficient to pull the armature down upon the magnet, and so actuate the semaphore; but to guard against wind pressure, dust, rust, and wear of rubbing parts, a current of 5 ampères is provided. In addition a reserve current of as much as 15 ampères is kept in store at the signal-box, and is at the immediate command of the signalman in any emergency. From the full line in the diagram shown in Fig. 15, Plate 72, it will be seen that with 5 ampères an initial pull is given of 8 lbs., at a distance or range of $3\frac{1}{2}$ inches; which is more than double what is required to work any signal arm properly fitted; and the home pull is 321 lbs.

If the same strength of current were necessary to hold signals down as to pull them down, the use of a continuous current would be prohibited by its cost. But a current of only 0·1 ampère is more than sufficient to hold a signal down; and it is found that a continuous current of 5 ampères for moving the signal, and of 0·1 ampère for retaining it, yields an economical result. Accordingly when the armature has finished its stroke and moved the signal, it is made to switch in automatically a resistance-coil which reduces the maximum or moving current of 5 ampères to the minimum or retaining

current of 0·1 ampère. The resistance-coil can take the form of an incandescent lamp, which then serves as an indicator or tell-tale in the signal box, as shown at L in Figs. 17 and 18, Plate 72.

In excess of the greatest possible requirements, it may be assumed that the whole time during which each signal is needed to be held down to show line clear is 12 hours out of every 24; and that the number of times each signal has to be lowered in the 24 hours is 150; and that the time occupied in each lowering is 2 seconds. Assuming also 10 ampères instead of 5 as the lowering current, and 0·2 ampère instead of 0·1 as the retaining current, and 5 ohms as the resistance R, then the electromotive force E corresponding with the lowering current C is equal to $C \times R = 10 \times 5 = 50$ volts; and assuming 746 watts = 1 HP., the horse-power is equal to $C \times E \div 746 = 10 \times 50 \div 746 = 0 \cdot 6703$ HP., which has to be exerted during 150 lowerings × 2 seconds = 300 seconds = $\frac{1}{12}$ hour, and is therefore equivalent to 0·05585 HP. exerted continuously throughout one hour. The retaining current C of 0·2 ampère corresponds with an electromotive force $E = C \times R = 0 \cdot 2 \times 5 = 1$ volt; and the horse-power is $C \times E \div 746 = 0 \cdot 2 \times 1 \div 746 = 0 \cdot 00027$ HP., which has to be exerted during 12 hours in each day, and is therefore equivalent to 0·00322 HP. exerted during one hour. Hence the whole power to be provided per day is 0·059 HP.-hour per signal. This is exclusive of inserted resistance, such as a glow lamp, for which 250 ohms must be substituted instead of 5 ohms in calculating the retaining current; the extra 245 ohms involve an additional expenditure of 0·158 HP.-hour, making a total of 0·217 HP.-hour per signal per day. Allowing 50 per cent. loss in the battery, and according to well recognised electrical data 2*d.* per HP.-hour, the cost of providing such an amount of power would be less than one farthing per signal-arm per day without inserted resistance, and less than nine-tenths of a penny with inserted resistance. But inasmuch as the number of lowerings would not be so many as 150, and the lowering current would not be so high as 10 ampères, and the retaining current would not continue in operation so long as 12 hours, the true result would be reduced to about one-sixth of the above.

The foregoing remarks respecting the electric current employed to actuate the magnets apply to the use of secondary batteries; and the results obtained from these accumulators of electrical power are very satisfactory and economical. In certain cases however it may be preferred to use a primary battery, such as the Lalande oxide of copper battery, the working of which is very easy and reliable. The constant and economical current it gives can be used not only for actuating the magnets, but also for lighting the lamps on the signal posts and at the points. With a primary battery. the reduction of the current from a moving to a retaining current cannot be effected in the same way as with a secondary battery, by switching a resistance in; but the same levers and switches are still available for switching *out* the large battery which gives the stronger moving current for lowering the signals, and switching *in* a smaller battery, of smaller cells and with greater internal resistance, which gives the weaker retaining current for holding the signals down.

Railway Points.—In Figs. 20 to 24, Plates 72 and 73, are shown the magnets and gearing for working a pair of railway points; these magnets are practically of the same construction as for working signals, but are of larger size, and are wound with copper tape instead of wire in order that they may take a maximum current with a minimum of resistance. With a current of 23 ampères and an electromotive force of 40 volts, the force of the pull is as shown by the dotted line in Fig. 15, Plate 72, commencing with an initial pull of 33 lbs. at $3\frac{1}{2}$ inches distance, and increasing to 54 lbs. at 3 inches, and to a home pull of 1064 lbs. As will be seen from Fig. 21, Plate 73, the points are pulled over and held in either position by the sliding rod R, which is worked by the lever L, and is locked by the locking bolt B. The slot in the rod R is made $\frac{1}{2}$ inch longer than the width of the lever L working in it, so that the first $\frac{1}{2}$ inch of travel of the lever withdraws the locking bolt B by means of the incline I on the extremity of the lever, before the lever acts upon the sliding rod R.

Where a pair of points are covered by a signal, the locking bolt B —in conjunction with the armature of the magnet which pulls the

points over into the position corresponding with the signal when down for line clear—completes the circuit which enables the signalman to lower the signal. The signal is checked by its automatic repeater in the signal-box. The other point-magnet completes with the locking bolt the circuit which works a repeater in the signal-box.

Advantages.—The advantages of working signals and points by this system are that their distance from the signal box is immaterial, inasmuch as the electric working gets rid of all the mechanical difficulties which arise from excessive expansion and contraction of lever wires and from the severe pull required to work them through long distances.

Signals.—It is only during the continuance of the electric current that the signal can be held at caution or line clear; its normal position is at danger, to which it returns automatically on the cessation of the current, or if anything goes wrong; and in this position it is locked by simple mechanical means, and not by any electric agency whatever. Each signal is worked by its own magnet, and has a repeater or tell-tale in the signal box in the shape of a small arm R, Figs. 27 and 28, Plate 75, which shows the position of the signal-arm. If it is desired, the repeater is arranged to show the exact travel of the magnet armature working the signal: that is, if the armature stops half way, the repeater arm would stop in the same position; in fact any arrangement that may be desired can easily be effected. At the instant of contact between the armature and the magnet, there is a momentary cessation of the main current; and the tell-tale arm indicates this by falling back a little from its extreme position. This affords another infallible check as to the correct working of the magnet. The reduction of the current from a moving to a retaining pull takes place automatically at the moment of the armature reaching the magnet.

Points.—The advantages in working points by these electro-magnets are as great as in the case of signals. Either can be worked at any distance from the signal cabin. There is no need for a cabin to be put up, or a stand of levers, to work any special set of points

and signals; any number of points and signals can be worked from a small cabin, and can be locked and interlocked with absolute certainty. They can be so arranged that, if any wrong lever is moved by the signalman in arranging any combination, an alarm bell is rung in the cabin, and the signals already lowered go back to danger: the mechanical and electrical parts being so arranged as to provide a perfect check, without the intervention of manual labour or the will of the signalman.

Application to Railway Junctions.—In Figs. 25 to 28, Plates 74 and 75, is given an illustration of the application of this electric system to working the signals and points of an ordinary junction where there is a double line of way both on the main line and on the branch. The signal-box is here divided, as regards the electrical connections, levers, and switches, into thirteen divisions, 1 to 13, Fig. 25.

Suppose an up main-line train is required to be turned into the branch, Fig. 25, Plate 74, it will be necessary to work the points P 6, and the three signals on the up main line, namely the distant signal S 1, the home signal S 3, and the station signal S 5. The lever of the points P 6 is first pulled over in division 6 of the signal-box, whereby an electric connection is made between 6 and 7, the up-branch points being thus set right for the up train to pass into the branch. The down-branch point-lever 8 must be back or in its normal position, in order to let the current pass through to division 3 and thence to division 2 for lowering the home signal S 3. As soon as the signal-lever 3 is pulled over and the signal lowered, the current can pass on to 1 for enabling the distant signal S 1 to be lowered. Last of all the current can pass through 5 and thence to 4 and 10 for lowering the station signal S 5.

Suppose another case of a train approaching the junction on the down branch, to pass upon the down main line; the home and distant down-branch signals S 12 and S 13 will have to be lowered. The points P 8 must first be in their normal position, and their lever 8 must be back, before the electric current from the battery can pass through 8 to 12, and thence to 10 for lowering the home

signal S 12, and afterwards to 13 for lowering the distant signal S 13. It is now impossible to lower the home and distant signals S 10 and S 11 of the down main line; because the current for working these signals is prevented from passing, by the act of pulling forwards the lever that belongs to the home signal S 12 of the down branch.

For station to station signalling, Figs. 26 to 28, Plate 75, the transmitter and receiver instruments are used in somewhat the same way as in ordinary railway working. The continuous current used makes the working very simple and easy and reliable. The signals and points are actuated by a main current; and this is checked and controlled by a subsidiary current, which works the transmitter and receiver instruments. A train travelling along any section of line protects itself by passing over contact levers or treadles T, both on entering and on leaving the section; the depression of the treadles by the deflection of the rail breaks the current which holds the signal-arms down, and sets them free to fly up to danger automatically.

Discussion.

Mr. Timmis exhibited the working of a full-sized signal which he had had at work in his office in Westminster for a considerable number of months without the slightest hitch occurring at any time. At the Gloucester Wagon Works there had also been working since last December five signals—a distant signal, a home signal, and three station signals; all actuated by an electric current from Faure-Sellon-Volckmar secondary cells. They had been worked during severe thunder-storms and during severe gales of wind. In a heavy thunder-storm that occurred some months ago they were worked during the whole of the storm; they were simply kept working up and down in every possible way, proving what electrical engineers were all thoroughly convinced of,—that no thunder-storm and no electrical

disturbance could affect the working of the signals by a primary or a secondary battery. In addition there had for several months been working at Gloucester a set of points, kindly sent there by the chief engineer of the Great Western Railway, Mr. Owen, to be fitted up and worked with the electro-magnets, as shown in Plate 73. No difficulty whatever had been experienced in pulling over these points at any time under any conditions that had at present been met with. Of course in heavy falls of snow, and in other conditions which did arise in rough railway work, objections might be raised that the points could not be pulled over; but then it was very well known that the existing points had now to be watched in heavy snow-storms; and he was convinced that there was not so much difficulty in working a pair of points by a current from the electro-magnets as there was by the present manual method.

Another fact which he wished to mention was that last spring he had been asked by the manager of the Swansea Dock and Harbour Trust, Mr. Capper, to fit up a signal lamp on the ground. Ascertaining however that there was always an objection to signal lamps on the ground, because careless or mischievous persons were apt to give them odd kicks that did them no good, he had suggested that instead of a ground lamp a small signal should be put up, five-eighths the size of an ordinary signal, and at such a height that when the signal arm was down to show line free its lowest point should be rather over 7 feet above the ground. All the signal wires being carried overhead or underground were out of sight, and out of sight here meant out of mind to any persons who might otherwise be tempted to injure them; so that there was no danger of their being damaged in any way. That signal had been fitted up about four months ago, and the report he had received a few days since was that it had been working for the regular traffic during the whole of the time without a single hitch of any kind. The system, if it was successful, would of course create such a revolution that the amount of work to be got through before it could be extensively adopted would be very heavy. Naturally revolutions of that kind in this country were not effected unless they went silently and slowly, and perhaps for that reason they were all the more sure.

(Mr. Timmis.)

Upon one point which had been stated in the paper he desired especially to insist: namely that if anything did go wrong—and of course there was always a liability to go wrong, no matter how perfect the contrivance—the signals went back to danger; and it was clearly a great advantage for an engine-driver to feel perfectly certain that, if anything went wrong, he could trust to the signals going to danger and stopping him from getting into difficulty.

In reference to the working of the electric currents, he wished to point out to those who understood the management and working of electricity that it was one thing to have constant work on a battery and another thing to have intermittent work. A very exhaustive series of experiments, extending over a considerable number of months, had been lately carried out by Mr. Currie, who had found that, if a set of wires through which a constant current was being sent were large enough to take it without injury and without heating, then by substituting an intermittent instead of a constant current it was possible to send four times the strength of current through the same wires without injury and without heating. This he thought was a valuable fact to know, because at times the knowledge of it might become very useful.

Another point to which he desired to refer was the breaking of contacts. The signal which had been lowered for enabling a train to leave a station was sent back to danger automatically by the train passing over what was called a contact-breaker, which was not exactly a treadle. Treadles had been used for a number of years, or rather a great many experiments and trials had been made with them; but it was an absolute impossibility, he maintained, to get a treadle that could be perfectly reliable for making contact for the passage of an electric current. On the other hand there was no difficulty at all in making a treadle, or he would rather call it a contact-breaker, which should break a current with absolute certainty. That point should be mentioned, because otherwise it might perhaps be imagined from a cursory reading of the description given in the paper (page 454) that the treadles or contact-breakers were used for making contacts: whereas he disapproved altogether of so using them, and they were arranged for breaking contact instead of making it.

From the working of the signal now exhibited, it would be clearly seen that pulling it down was one point, and holding it down was another point. The pulling current lowered the signal-arm by pulling the armature down on to the bobbin of the magnet. Using here a primary battery—the Lalande oxide of copper battery—the reduction of the current from the pulling current to the retaining current was done in the way usual with a primary battery, namely by switching out a given number of the cells, leaving only a sufficient number of cells in action to hold the armature down on the top of the bobbin. In order to illustrate this practically, he had here interposed in the course of the retaining current a small lamp, which was seen to be glowing brightly as soon as the pulling current was reduced. There was also in the signal cabin a little repeater arm, indicating the position of the signal outside; and after the signalman had put his switch over for pulling the signal down, the moment it was down he saw this little indicator fall, and was thereby absolutely certain that the signal must be down, because the current to work this indicator came back to him through the armature after it was actually down on its bobbin. The moment he saw this, he wanted to get rid of the excessive expenditure of maximum or pulling current; and accordingly let go his switch, which flew back with a spring and thereby switched out a given number of cells in the primary battery. With a secondary battery the handle flying back would switch a resistance in, such as the little incandescent lamp now exhibited. The glowing of this lamp in his cabin showed the signalman that he was then using the minimum or retaining current. As soon as ever the electric current was broken, the lamp immediately went out, and the little indicator in the cabin went to danger, showing that the signal-arm outside had also gone back to danger. Specimens were shown of the treadles as fitted up for breaking the contact when the train passed over them, and thereby letting the signal fly back again automatically to danger. The lock and block instruments, which were also exhibited, were those used for signalling from one station to another. When a train from station A, at which was placed one of these instruments, was passing station B, where the other instrument was placed, then in going over the treadle there

(Mr. Timmis.)
it freed the instrument at station B, thereby telling the signalman at B that it was passing him. Then, and only then, was he able to give permission to the signalman at station A to lower his signal at A for permitting another train to follow towards B.

Mr. R. E. B. Crompton said that, although he had not studied this particular branch of electricity and magnetism, he had followed the paper with very great interest; and he congratulated the author on the successful manner in which he had worked out a very intricate subject. To himself the working out of the involved interlocking arrangements illustrated in Plates 74 and 75 was exceedingly interesting; and he thought it would lead mechanical engineers to form a rather high opinion of the care and forethought which had been exercised in maturing so elaborate a plan. No doubt most of those present would agree with himself in believing that they were on the eve of a great change in regard to the mechanical transmission of power. Much that was now being done by connecting-rods, by ropes, by chains, by compressed air, and even by hydraulic power, would hereafter be done by electric transmission. Perhaps all engineers were not aware how much had already been done in that direction. The fact was that electric lighting, to which such general attention had been directed, was nothing more nor less than electric transmission of power: so that those engaged in working out the transmission of the electric current for lighting had really at the same time been working out the transmission of power. It had been shown in the paper that a home pull of 1000 lbs. could be got with a comparatively small magnet; but there was at present the same sort of feeling in regard to this matter as he remembered there had been with regard to gas engines a few years ago. When the first gas engines were introduced, they were thought to be only powerful enough for working churning machinery at the agricultural shows; but no one at the present time would make a similar mistake. Electro-magnets used to be regarded as scientific toys, or at all events as capable of working only small signals; but when it was seen that at the present time a continuous pull of the character shown in Fig. 15, Plate 72, could be had at the distance even of

several miles, with an apparatus weighing less than 12 cwts., some idea could be formed of the means already existing for transmitting power by electricity.

One point that he wished to call attention to, because he considered it a real difficulty, was that of providing powerful electric currents along a long line of railway. Taken by itself, electric signalling to the extent foreshadowed in the paper would not be easy to introduce on such a line of railway. Wherever there was a large centre for the generation of electric energy, the matter would be simple and easy enough; but as things now stood, how were the secondary batteries to be charged? If one thing had been proved more than another, it was that what was called by Sir William Thomson a "box of power" was not a portable box. It was easy to put it down as a carefully arranged permanent battery, and then to charge it; but if it was jolted about in a railway wagon it would not last long; so that the expectation of storing power in that way, and then sending it away in wagons, had not been realised up to the present time. From primary batteries too he did not think that there was much to hope for. It was true they would give currents; but with the powerful currents required they were very expensive to work. Even the Lalande battery, mentioned in the paper, which he believed was a very cheap one, would be enormously expensive compared with the existing signalling arrangements. This question of cost was the first thing which a railway electrician would have to consider. Speaking from his own experience, he was at present engaged in introducing electric lighting of railway trains, and he found that the railway authorities would not hear of it unless he could show something satisfactory in the way of cost; in fact unless they could get the work done cheaper by electricity than by gas, they would not look at it. As he was able to show a large margin, on paper at all events, they would give it a fair trial, and were now doing so. Possibly the author of the paper had not hitherto dealt sufficiently with this question of the cost of providing electricity at the stations up and down the line.

With regard to the switches, he should be very glad to know how the author got over the difficulty, not of breaking the contact,

(Mr. R. E. B. Crompton.)

but of perpetually making and breaking contacts: because it was found in the case of switches, with a current even as low as 5 ampères, that where they were in such constant use the surfaces suffered very much. No sparkless switch had yet been invented. The difficulty would no doubt be got over, but at the present time it was a very troublesome one.

The long-pull magnet was one of many forms that had been brought before him when inventing arc-lamps several years ago; and he thought it was originally an American invention, called the "suck magnet" or the "plunger magnet." There were indeed some half-dozen forms of magnet by which the same result of a long steady graduated pull could be attained. Also he did not think it was to the credit of the arrangement described in the paper that the force of the pull should be adjusted by the application of a counterweight; the adjustment he considered ought to be managed without any such assistance, because the counterweight acted in opposition to the pull of the magnet, and so much power was thereby wasted. No doubt a useful locking arrangement was obtained by the use of the counterweight; but he thought the plan was not as good as it might be in that respect.

Mr. Sydney F. Walker could endorse what had been said by Mr. Crompton with regard to the great skill shown by the author in working out his apparatus. Naturally all electric engineers must be grateful to any one who would increase the demand for electricity, because it gave them all more work to do; and all railway engineers must welcome anything that would increase the safety of their passenger and goods traffic. He hoped therefore that a great future was before the system that had been described in the paper, or some system of the kind; and had long wondered that electricity had not been applied at an earlier period to the working of railway signals.

The present paper he thought had hardly done full justice to electricity. In the form of magnet here brought forwards, the subject appeared to him to be attacked at the wrong point. He certainly admired very much the mechanical part of the arrangements

described in the paper; so far as he understood the matter, nothing could be better or simpler than the automatic locking of the signal at danger, should any mishap befall the electric part of the apparatus. Electrical engineers knew well enough that electric apparatus did get out of order sometimes; and it was therefore a wise provision that if anything should get out of order the trains were stopped. But in the matter of electricity he thought some difficulties were raised in the paper which did not actually exist. For instance it had been stated in page 445 that, owing to some natural law as yet unsolved, it was impossible to get more than half an inch range of working pull. But so far was this from being the case that, if a piece of iron were brought near a dynamo machine, it would be found that the attraction would be powerful enough to draw it home from a distance of considerably more than half an inch. Moreover it had been stated that, although the pull might be increased by leverage, yet this method became too expensive, because the current was excessive and the impact too violent. But if the calculation were worked out, he believed it would be found that it was not so. It appeared from the figures given in page 449 of the paper that a pull was obtained of 8 lbs. at $3\frac{1}{2}$ inches distance. Now by the well known law stated in the paper, the pull between the magnet and its armature varied inversely as the square of the distance; therefore at half an inch the pull would be 392 lbs. But on the ordinary principle of the lever he made out that, taking a lever of 7 to 1 and using it at half an inch distance, only 56 lbs. direct pull of the magnet would be required at the short end of the lever for producing at the long end the pull of 8 lbs. which he gathered was amply sufficient in practice for working the nearly balanced signal-arm. The result would be that, taking the same current and everything else the same, a magnet could then be used of about one-eighth the size of that shown in the drawings, by employing in conjunction with it some simple form of multiplying gear such as a lever; and thereby he imagined the cost of construction and of maintenance would be considerably reduced. He agreed with Mr. Crompton that any desired pull might be obtained, and at any distance, if only the magnet were made big enough, and were so constructed that the lines

(Mr. Sydney F. Walker.)
of force would reach the armature: it was only a question of the mode of arranging the magnet.

As to the action of the solenoid magnet, there appeared to him to be some mistake in the paper. The construction had been carefully described, but it had been there stated that, when the central stalk or armature-rod inside the core was brought into a central position in relation to the magnetic field, the attractions became neutralised. The action of the solenoid magnet was simply that each coil of wire round the bobbin exerted its pull upon the central stalk, and as the stalk became gradually drawn into the bobbin, more and more coils of wire came into action. According to the law of the attraction varying inversely as the square of the distance, the central stalk or armature-rod, provided the forces opposed to its motion would allow of its doing so, would move into the position which it would have taken had the magnet been simply an iron bar with coils wrapped round it; and if the electric current were strong enough to retain it there, the armature would then remain in that position. It seemed to him therefore a mistake to think that all that the author had done could not be accomplished with an ordinary or solenoid magnet: though of course in the former case there would not be obtained a long pull direct. He agreed with the author in thinking that the solenoid magnet was more expensive than the ordinary magnet, because the whole required length of pull could not be got from it at once; but on the other hand a gradual pull could be got. The whole strength of pull and the gradual pull could not both of them be obtained, and one or other must be sacrificed; but all that was wanted for the purposes described in the paper might be got, he believed, without going out of the way to design a new magnet.

As to the impact of the armature closing upon the magnet, the home pull of 1064 lbs., shown in Fig. 15, Plate 72, or even the lower amount of only 321 lbs., also shown there, seemed to him enough to produce rather a heavy knock. But he saw no necessity for any impact at all of the armature upon the magnet; it would be easy to interpose some buffer to receive it, if necessary.

The construction of the magnet described in the paper, as had been pointed out by Mr. Crompton, dated back a long time. In

April 1876 a form of magnet somewhat similar to that shown in the drawings, but with a slight modification, had been brought before the Society of Telegraph Engineers* by Mr. John Faulkner of Manchester, who called it the Altandæ magnet. Having discovered that electricians were wasting a large amount of power by using two-legged or horse-shoe magnets, he had taken a single-bar magnet, and slipped an iron tube over it, placing a disc across one end, and facing the other end with another disc as an armature; in that way he got a greatly increased power, and he had exhibited some diagrams showing the magnetic waste and the magnetic economy as he called them. It was quite true that in the Altandæ magnet the attracting force was apparently concentrated round a small ring, while in the ordinary horse-shoe magnet it was dissipated to a certain extent. The matter had been taken up by Mr. C. V. Walker, the then President of the Society of Telegraph Engineers; and it had been found that, though the magnet would hold on and attract with a greatly increased force of pull, it nevertheless lost its power at a very small distance from the face, for the reason that the lines of force, being concentrated close to the face, were too much dissipated outside to give an effective pull at a distance. It therefore appeared to him that whatever was good in the magnet described in the present paper, so far as the long pull was concerned, was less than would be obtained with the old solenoid magnet, since additional work would have to be done in overcoming the strong attraction of the iron stalk for the iron tube into which it was entering in its immediate vicinity; and what was good in regard to the holding power was due to the Altandæ magnet.

It had been mentioned in page 446 that the armature must not be saturated with any working current; he should like to know the reason of that, if possible. As to the economy of the magnet, that was a point which he disputed. On page 449 a working current was mentioned of 5 ampères, and on page 450 the resistance of the circuit was given as 5 ohms. Now by the well known law that the work done was equal to the square of the current multiplied by the

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* Journal of the Society of Telegraph Engineers, 1876, pages 153 179.

(Mr. Sydney F. Walker.)

resistance of the circuit, the work in this case would be 125 watts, or roughly about one-sixth of a horse-power, or about 90 ft.-lbs. per second; and taking two seconds for the duration of the pull, as stated in the paper, the pull would be equivalent to a force of 180 ft.-lbs. exerted for one second. For that expenditure of energy—which meant a still greater expenditure in the generator, no matter what it might be—the magnet gave out a force of only 8 lbs. $\times$ $3\frac{1}{2}$ inches = $2\frac{1}{3}$ ft.-lbs., which he thought hardly confirmed the statement as to economy. Similarly in the case of railway points, it would appear from page 451 that they required actually as much as $23 \times 40 \div 746 = 1\frac{1}{4}$ H.P. to pull them over. The whole plan he believed might be carried out at much less expense than was foreshadowed by the arrangements described in the paper, in which he would suggest that the currents used were altogether too large, and that instead of 5 or 10 ampères the current might be brought down to one-tenth or one-twentieth of an ampère, even if working with secondary batteries, and still lower if working with primary batteries. The great difficulty to contend with in primary batteries was that, when furnishing large currents, electrolysis went on so fast that secondary cells were formed, and the batteries required frequent attention. So long as only small currents were being furnished, there was no difficulty in getting a battery that would last a long time. As an instance he might mention that he had frequently put electric signals into colliery shafts, and had never had occasion to give any attention to the batteries for twelve months. In such cases the current would perhaps be only one-twentieth of an ampère or less, which was looked upon as a large current to use, and was necessary because powerful blows were required to be given by it. The power used in working those signals he considered was as great as was wanted for the work described in the paper. There was no difficulty in constructing an electro-magnet to give a large power with a small wire and with a small current; it was only necessary to provide an increased number of cells, in each of which the consumption was then so much lessened that there was a great gain; and he ventured to suggest that the author of the paper would gain largely by some step in that

direction. The notion that an effective pull could not be got at a distance of more than half an inch had probably arisen from the fact that electro-magnets were rarely constructed to pull through a distance of so much as half an inch. For ordinary work no one would construct such a magnet to pull through so much as half an inch, unless for some special reason; owing to the great advantage gained by having the armature close to the magnet, it should be brought as close as it possibly could be.

The suggestion which he had made, of working with a smaller current, would also get rid of the complication of switching a resistance in. That was a complication which he thought might cause trouble. The troubles that were experienced with switches and contacts had been mentioned by Mr. Crompton, whose statement he could thoroughly endorse. There was nothing more troublesome than keeping surfaces clean through which electric currents had to pass. The larger the current, the more difficult it was to keep them in order, owing to the constant sparking. If the work were done with as small a current as possible, he would suggest that, even though more material were consumed through keeping the full current on for the whole time, it would be cheaper than having to employ skilled attendants for keeping the switches in order. With a primary battery it had been stated in the paper that the reduction of the current could not be effected by inserting a resistance, as could be done with a secondary battery; but he thought that was a mistake, and that the reduction might be effected in whichever way was most convenient, either by throwing a resistance in or by cutting off a number of cells. Whatever could be done with a secondary battery could be done equally well with a primary battery; the difference was only in the cost.

What had been said by Mr. Crompton about the difficulty of providing the power, he could also endorse. If secondary batteries could be provided which would want charging only about once a month or once in three months, it would not be a serious matter to bring them in turn to the charging station and have them replenished. But with such large currents as those dealt with in the paper it did not appear to him that this could be done; and he did not see how the

(Mr. Sydney F. Walker.)
batteries on a large railway were to be charged continuously. If a wire had to be led to the signal battery from the dynamo at the station, the current which charged the battery might just as well be caused to do the work direct. Carrying secondary batteries to and fro would be found to be a serious matter; and it had been pointed out by Mr. Crompton how different a case it was when everything was nicely at hand, from what it was when the secondary battery was perhaps miles away from any dynamo.

While certainly admiring the ingenious way in which the author had arranged that the signal could not be given until the points were right, he feared that unless that plan was very carefully worked out there would be some trouble with the contact. It had been mentioned that in the author's arrangement he only broke the contact: that plan was of course a very good one, but in order to break a contact it must first have been made. It was therefore only putting off the difficulty one degree further.

Mr. Henry Davey asked what was the number of cells which were required in a primary battery for working the signal now exhibited; the number here in use for the purpose appeared to be very considerable. Quantitative knowledge was of more importance to a mechanical engineer than an array of principles; and he should be glad to know both the number and the description of the cells in the battery, in order to judge of the power required to do the work.

Mr. Timmis replied that the number of cells required to work the signal was certainly large. It appeared to be a formidable array, and so it was; but the same number of cells that were here required to work the one signal now exhibited would work equally well a dozen or a score of signals. There must be a given number of cells for a given amount of electromotive force. It might be true theoretically, but it was not so in reality, that a current of one ampère obtained from a single cell had the same strength as a current of one ampère produced from a number of cells; but the amount of battery power required to give the current necessary for pulling the armature and lowering

only one signal was equal to the work of lowering a great number of signals. The number of cells used at Gloucester for working one pair of points and six full-sized signals was twenty; but if the number of signals was doubled, they could be worked with perfect ease with those same twenty cells. Of course the volt force of the Faure-Sellon-Volckmar cell was practically double that got from the Lalande cell. The cells in the Lalande battery exhibited had each a volt force he believed of rather over 0·9, and it might be taken that the electromotive force of a Faure-Sellon-Volckmar cell was 2·0 volts.

A difficulty had been thrown by Mr. Crompton over the whole system described in the paper, because of having to face the transmission of power in some way or other from point to point. It was quite true the transmission of power had to be faced; but there was a difference between the transmission of power contemplated in the paper, and that dealt with by Mr. Crompton. If it had been necessary for the signals to be worked from all the signal boxes by means of secondary batteries, the difficulty would unquestionably have been too great to face; but he had no doubt whatever, judging not from theory but from actual practice, that the work could be done wherever it was wished with secondary batteries, and wherever desired with primary batteries, if the conditions were favourable for the latter. At Swansea, where as already mentioned one electric signal had been fitted up, there would before long be a great number of signals, all working from one or at most two batteries, which were being charged regularly every six weeks without any difficulty at all, by means of dynamos that were used for lighting. At big stations like Derby, Crewe, Swindon, and many others, there was an amount of motive power ready at any time, which could be used without any practical expense, because it could be utilised in idle moments for running a current from a dynamo so as to re-charge the batteries as they were run down. That did not appear to him to be a very extravagant idea in reference to the transmission of power. In small stations, where there were not those conveniences of available motive power, it was intended to employ the Lalande oxide of copper battery, which was already in use in such cases. The current that

(Mr. Timmis.)

was being used from this battery was an intermittent one, and its amount could easily be calculated from the figures given in the paper. It was a fact that the oxide of copper battery did not want touching oftener than once in six weeks; and he believed it would not want touching oftener than once in three months. At any rate it seemed a little unreasonable to find fault with an apparatus because it wanted some care or attention once in the space of six weeks. The weight of a primary battery was by no means great. Each cell of the Lalande oxide of copper battery did not weigh more than about 14 lbs. The cells of the battery now exhibited, it was true, were rather heavy, because they happened to be the only ones he could get for this meeting from M. Lalande's representatives; but they were now being made so light that a whole battery for an ordinary junction, such as was represented in Plates 74 and 75, would not weigh more at all events than 8 cwts.

Exception had been taken by both Mr. Crompton and Mr. Walker to the shape of the long-pull magnet described in the paper, and to the principles on which it had been worked out; and it had been represented by Mr. Walker that just the same result could be got from an ordinary solenoid as was obtained with the Currie magnet. On the contrary his own experience had led him to the decided conclusion that no such results could be got from an ordinary solenoid; and it appeared to him that the principles of the long-pull magnet were far from being rightly understood. It had been calculated by Mr. Walker that, if at $3\frac{1}{2}$ inches the pull was 8 lbs., then at half an inch it ought to be 392 lbs.; whereas it would be seen from the diagram, Fig. 15, Plate 72, that at half an inch the actual pull was 70 lbs. This result could only be explained by the peculiar construction of the magnet itself, as shown in Fig. 1, Plate 70, in which it would be seen that, so long as the bottom end of the central stalk A of the armature was at any distance above the top of the tubular core of the magnet, there was an attraction set up between the top edge of the tube and the bottom edge of the armature-rod; but as soon as these two edges passed each other, by the rod entering into the tube, the local currents that were then set up between them caused a sort of brake power to act upon the rod,

which retarded it from falling any lower into the tube. When this position had been reached, and the brake action was thus retarding the central stalk A, the outside rim or flange F of the armature was now within the range of attraction of the outside casing B of the magnet, and of course the increase of attraction between B and F was then inversely as the square of their distance apart; but as soon as the bottom edge of F and the top edge of B had passed each other, the brake action came into force between them, and retarded the further fall of F. In this position it was that the flat cap or disc D on the top of the armature stalk came within the range of attraction of both the tubular core C and the outside casing B of the magnet. If the brake power were not exerted in the way he had now described, it was perfectly clear, as had been shown by Mr. Walker, that, instead of the pull of 8 lbs. at $3\frac{1}{2}$ inches being increased to 70 lbs. at $\frac{1}{2}$ inch, it would be increased to 392 lbs. The fact therefore of the pull at half an inch distance being only 70 lbs. appeared to him a sufficient proof that the increase of power as the armature approached the magnet was retarded by this brake action.

These remarks were also his reply on the question as to whether the pull of the magnet was regulated electrically, or whether it was regulated by the counterweight. The absolute weight of the counterweight was nothing like sufficient to regulate the pull in the way in which it was actually regulated. By variously adjusting the shape and length of the centre rod A of the armature, and the shape, length, and thickness of the rim or flange F, he had succeeded in so modifying the pull as to bring the diagram to almost any curve desired. Only recently he had sent over to New York a full-sized magnet, exactly like the one now exhibited, and with an armature of the same shape, and had sent with it also three or four additional centre-rods and rims, of different shapes and sizes, some of the rims having their edges a little further off the outside casing of the magnet, and some a little nearer; and the effect of those different rims and different centre-rods was such that the diagrams obtained from their various combinations showed variations of pull to almost any extent required. That was a result which could not be got with an ordinary solenoid. Both Mr. Currie and himself were aware of what had been

(Mr. Timmis.)
done by Mr. Faulkner and also by Mr. Holroyd Smith; indeed he did not think there were any magnets which had not been tested in some way or other in the large number of experiments made by Mr. Currie and himself.

As to making the top plate or disc of the armature sufficiently thick to prevent saturation, what he meant was that it was better and more economical, in working with masses of metal which had to be electrically charged, that they should contain such an amount of substance as would enable them to take without absolute saturation the current they were required to work with.

In regard to the question of using a maximum pulling current and a minimum retaining current, he thought the figures given in the paper were very conclusive. He had understood from Mr. Webb of Crewe some time ago that his calculations would not be safe, as to the length of time the signals would need to be held down, unless allowance were made for their being so during one half of the whole time. This did not mean that anything like even a quarter of the signals in the country were held down during one half of the time; but in order to work out the principle economically for putting it into actual practice, the maximum duty must be assumed and provided for. In this view he had gladly accepted Mr. Webb's suggestion; and surely when it took not more than two seconds to lower a signal, which might then have to be held down for an indefinite period, it was far wiser to limit the expenditure of the maximum or pulling current to the two seconds of lowering, and then to use a minimum current for holding it down, than it would be to go on using the maximum current during the whole of the time. The suggestion of using the minimum retaining current not only for holding the signal down, but also for pulling it down, was in his own experience wholly impracticable; as was also the idea of doing this work by means of such weak currents as fully sufficed for the working of colliery signal-bells. Having himself experimented in all manner of ways, he was quite prepared at any time to demonstrate practically the truth of the conclusions he had arrived at.

The Chairman had great pleasure in calling upon the members to give a hearty vote of thanks to Mr. Timmis for the great pains he had bestowed on his paper, which had led to the long and interesting discussion that had taken place; and also for the excellent way in which he had practically illustrated the subject by the actual working of the signal exhibited.

MEMOIRS.

Walter Raleigh Browne, son of the late Rev. T. Murray Browne, honorary canon of Gloucester, was born at Standish, Gloucestershire, in 1842, and was educated at Trinity College, Cambridge, where he graduated in 1865 as nineteenth wrangler and tenth classic, obtaining his fellowship in 1867. He afterwards served his apprenticeship to engineering with Messrs. Losh Wilson and Bell, Walker Iron Works, Newcastle-on-Tyne; and with Mr. Thomas Howard, resident engineer of the Bristol Dock and Harbour Works. He was for a short time a partner in the firm of Messrs. John Knight and Co., Cookley Iron Works, near Kidderminster; and subsequently managing director of the Bridgwater Engineering Works. He was elected a Member of this Institution in 1869, and was appointed secretary in 1878, continuing to occupy that position till January 1884. In 1872 (Proceedings, page 53) he contributed a paper on riveted joints; and in 1878 (page 617) a note on the theory of the action of brakes upon the wheels of a train. He was fellow of many scientific societies, and member of the Institution of Civil Engineers, from which he obtained two Telford premiums and one Telford medal for papers contributed to their Proceedings. In August 1884 he went to Canada to attend the meeting of the British Association; but was suddenly attacked with typhoid fever, and died at Montreal on 4th September 1884, at the age of forty-two.

Henry Allason Fletcher was born near Cockermouth in 1834, and was descended through younger branches from the ancient family of Fletcher of Cockermouth Hall. Two of his brothers represented Cockermouth in parliament. After having been educated at a private school, he received a practical training as a mechanical engineer in the works of Messrs. Gilkes Wilson and Co., Middlesbrough. He then became the managing partner in the firm

of Messrs. Fletcher Jennings and Co., Lowca Engine Works, near Whitehaven. These works had been established in 1794 by Adam Heslop, the inventor of an atmospheric engine which for many years competed successfully in the north of England, and especially in Cumberland, with the earlier invention of Watt. Of the Heslop engine he gave a description to the Institution in 1879 (Proceedings, page 85). In connection with engineering work he introduced several improvements, including a mineral tank-locomotive much approved in various parts of England and Wales. He was an active magistrate for the county of Cumberland. In consequence of failing health he had to relinquish business in the spring of 1884; and after a long and painful illness he died at his residence, Croft Hill, near Whitehaven, on 6th July 1884, at the age of forty-nine. He became a Member of the Institution in 1858.

Edward Edwards Hewett was born at Oxford on 17th July 1843, being the son of Mr. John Hewett, who was for many years secretary of Messrs. John Brown and Co., Sheffield. After serving an apprenticeship under Mr. Matthew Kirtley in the locomotive works of the Midland Railway, Derby, he obtained an appointment under Mr. Alfred L. Sacré in the works of the Yorkshire Engine Co. near Sheffield, where he held for some time the position of assistant works manager. In 1869 he was engaged in the steel works of Messrs. Vickers Sons and Co., Sheffield; and in 1872 he became chief assistant to Mr. R. Heber Radford, with whom he was engaged for a period of ten years. Subsequently he commenced business on his own account as consulting engineer and patent agent in Sheffield, where his death took place on 6th October 1884, at the age of forty-one. He became a Graduate of the Institution in 1865, and a Member in 1867.

Henry James Jackson was born in London on 5th September 1824. In 1855 he went to India in charge of the engines in the steamship "Harbinger" for Messrs. W. S. Lindsay and Co., and remained there some four years. On returning to England he was employed by Messrs. John Penn and Sons for several years as

engineer in charge of their engines and machinery in the "John Penn," running between Dover and Calais; the vessel on many occasions made four trips in the twenty-four hours. He was next appointed by Mr. Penn to be engineer in the steam yacht "Mahrousseh," built by Messrs. Samuda Brothers for the Viceroy of Egypt, and engined by Messrs. John Penn and Sons. Afterwards he became chief engineer for the Viceroy, and was created a Bey. On leaving that service he became superintending engineer to the General Steam Navigation Co., retaining this position until his death, which took place at Deptford on 2nd November 1884, at the age of sixty. He devised an improved propeller, which has been adopted by many steamboat companies. He became a Member of the Institution in 1876.

George Peaker was born on 20th November 1838 at Bretton West, near Wakefield. After having served his time as a mechanic partly in Wakefield and partly in Leeds, he entered the Royal Gun Factory department, Woolwich, on 5th June 1865; and on 29th March 1867 entered the Royal Laboratory department as draughtsman, where he remained until 27th September 1869. He was then appointed to proceed to Kirkee in the Bombay presidency, India, to superintend the erection and fitting up of a factory for the manufacture of small-arms ammunition and other war material. He was subsequently appointed managing engineer to the factory, and retained this position until his death, which took place at Kirkee on 14th June 1884, at the age of forty-five. He became a Member of the Institution in 1874.

George Richardson was born at Oldham in March 1845, being the elder son of Mr. William Richardson, at that time engaged in the works of Messrs. Hibbert and Platt, and afterwards a partner and director in the subsequent firm of Messrs. Platt Brothers and Co. After attending a local school he was sent to the Chester College, then under the management of Mr. Arthur Rigg. Subsequently he spent eighteen months at Zurich, acquiring a thorough knowledge of German and French; and on his return he studied at Owens College,

Manchester. He next received a commercial training in the foreign office of Messrs. Platt's agents in Manchester; and then as an apprentice passed through all the departments of Messrs. Platt's works. Afterwards he was sent out to Rouen and other places in France, in company with Mr. S. R. Platt, to erect machinery made in Oldham. On the incorporation of the firm of Messrs. Platt Brothers and Co. in 1868, he was made one of the directors, on the recommendation of the late Mr. John Platt, M.P. On occasions of his father's absence, he was the responsible manager of several departments of the works, having the control of large numbers of workmen. With a view of making himself acquainted with all important improvements in mechanical engineering, he visited the principal manufacturing towns in the United Kingdom and on the Continent; and in 1879 paid a visit to America with the same object. His death took place at Oldham on 10th October 1884, at the age of thirty-nine, from cancer on the left lung, from which and from rheumatic gout he had suffered for some time. He became a Member of the Institution in 1881.

INDEX.

1884.

Fig: 1. *Flat Draw-bar.*

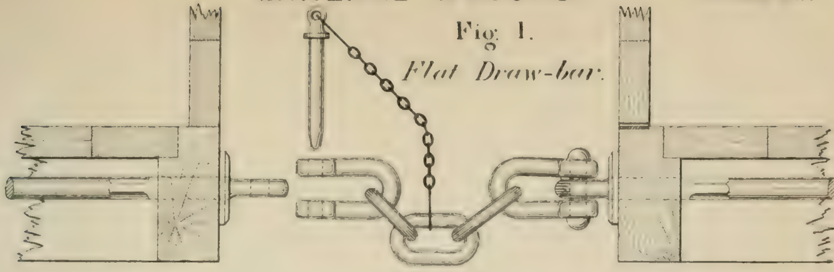


Fig: 2. *Plan of Fig. 1.*

Fig: 4. *Plan of Fig. 3.*

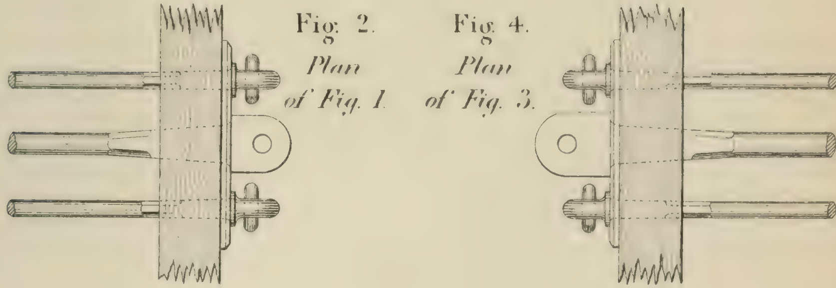


Fig: 3. *Jaw Draw-bar.*

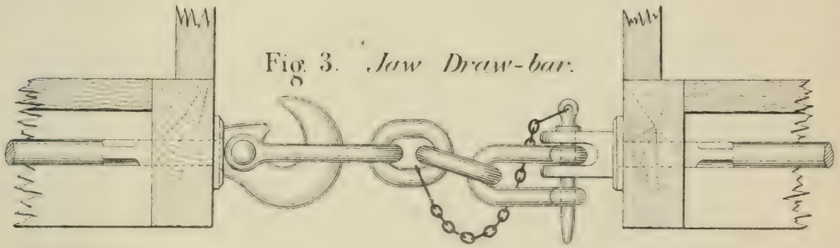
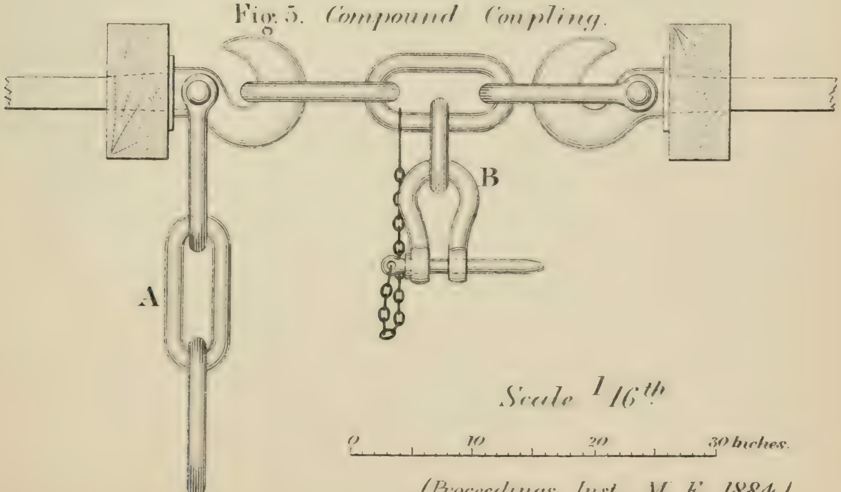


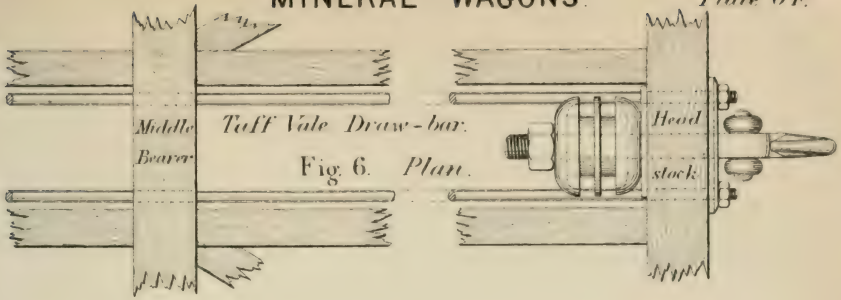
Fig. 5. *Compound Coupling.*



Scale 1/16th

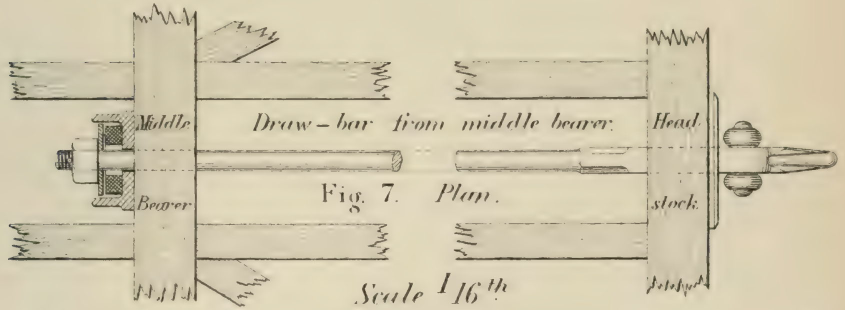
0 10 20 30 Inches.

MINERAL WAGONS.



Taff Vale Draw-bar.

Fig. 6. *Plan.*



Draw-bar from middle bearer.

Fig. 7. *Plan.*

Scale 1/16th.

Ins. 12 6 0 1 2 3 4 Feet.

Laminated Spring for Draw-bar and Buffers.

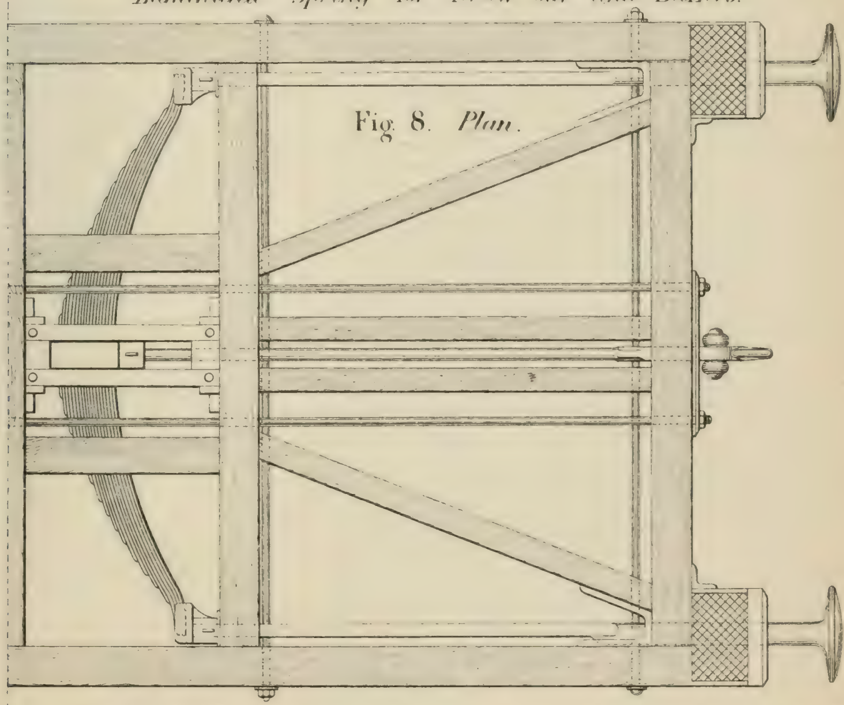


Fig. 8. *Plan.*

Scale 1/24th *Ins. 12 6 0 1 2 3 4 5 Feet.*

(Proceedings Inst. M. E. 1884.)

Outside Buffers.

Fig. 9.
Sectional Plan.

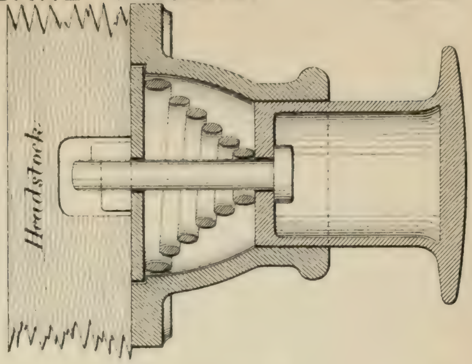


Fig. 10.
Vertical Section.

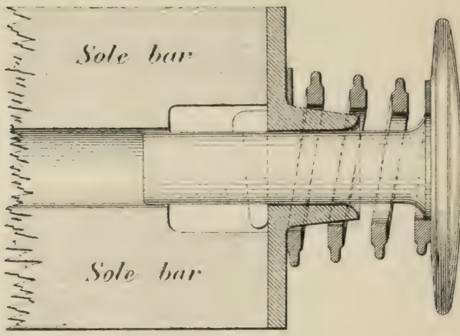
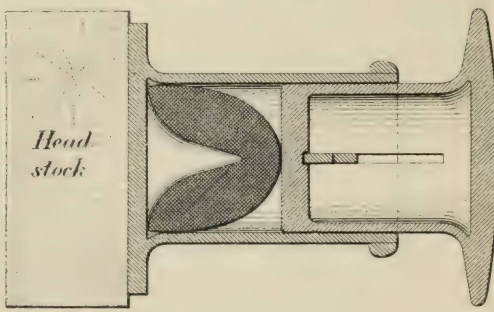
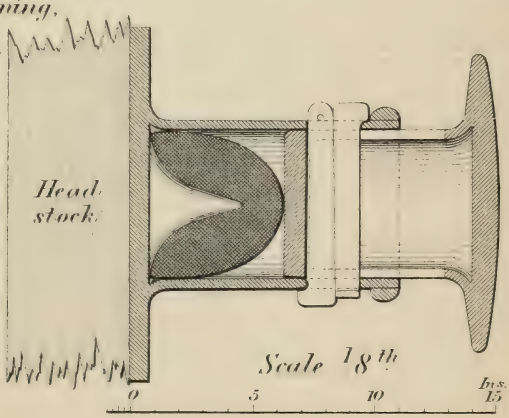


Fig. 11.
Vertical Section.



Wrought-iron Buffer with gib and cotter fastening, and india-rubber spring.

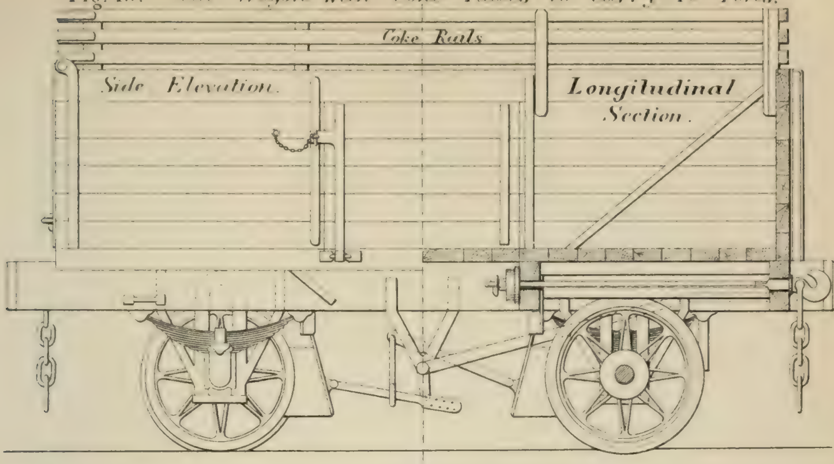
Fig. 12.
Sectional Plan.



MINERAL WAGONS.

Plate 66.

Fig. 13. *Coal Wagon with Coke Rails to carry 10 Tons.*



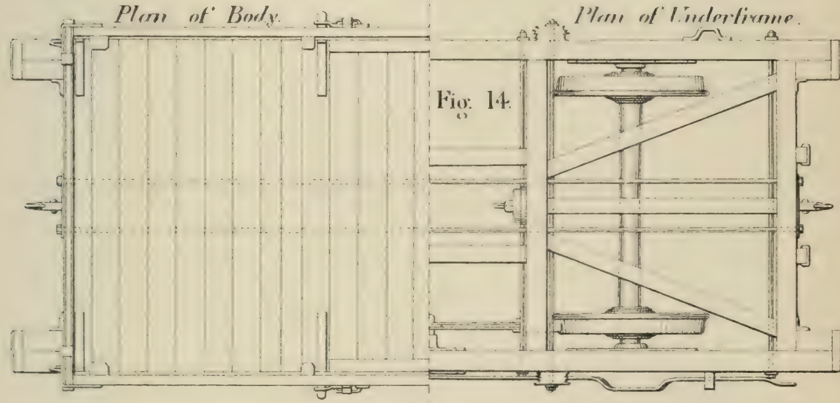
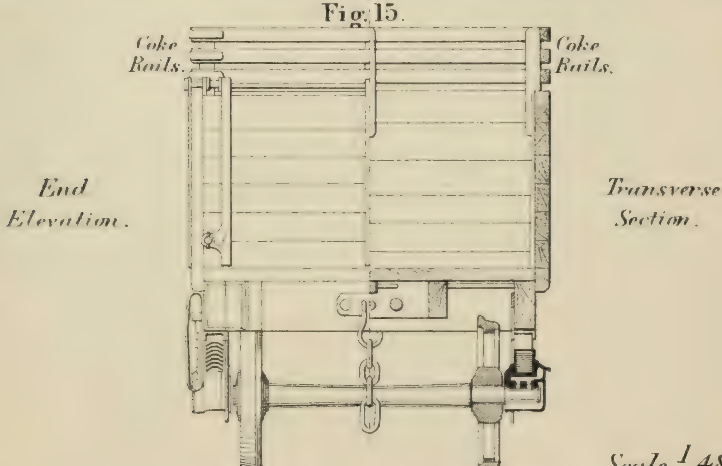


Fig. 15.



Scale 1/48th

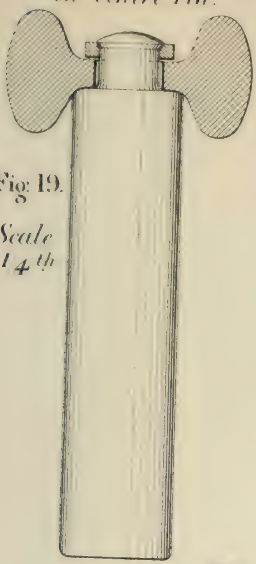
Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet.

(Proceedings Inst. M. E. 1884.)

Section of Cradle-Rail on Centre Pin.

Fig. 19.

Scale 1/4th.



Iron-ore and Rail Wagon.

Fig. 16. *Longitudinal Section.*

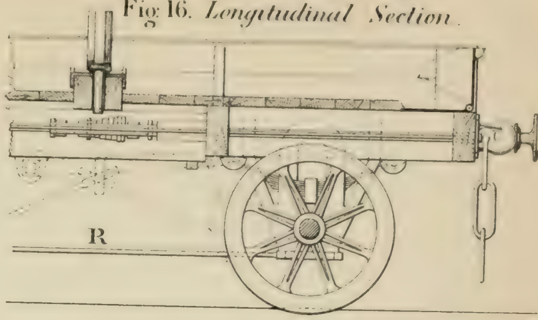
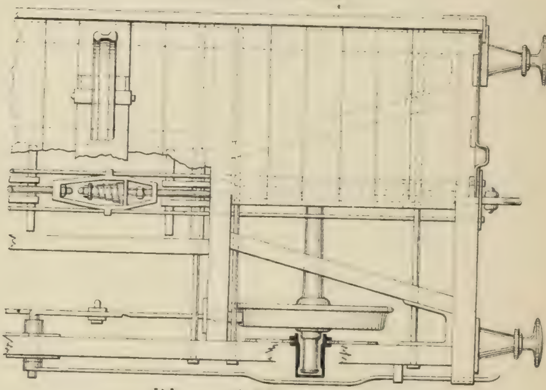


Fig. 17.

Plan of Body



Plan of Underframe.

Fig. 20.

Section of End Door and Bottom Plate.

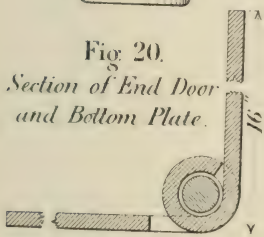
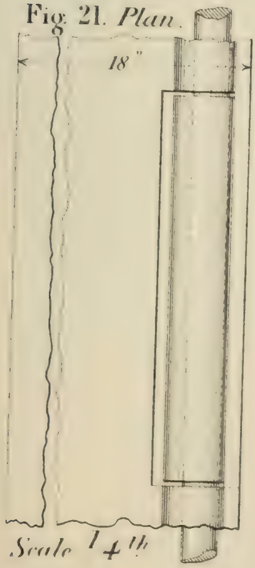
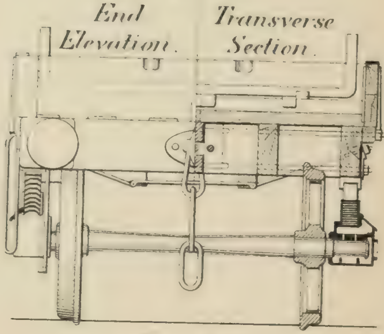


Fig. 21. *Plan.*



Scale 1/4th.

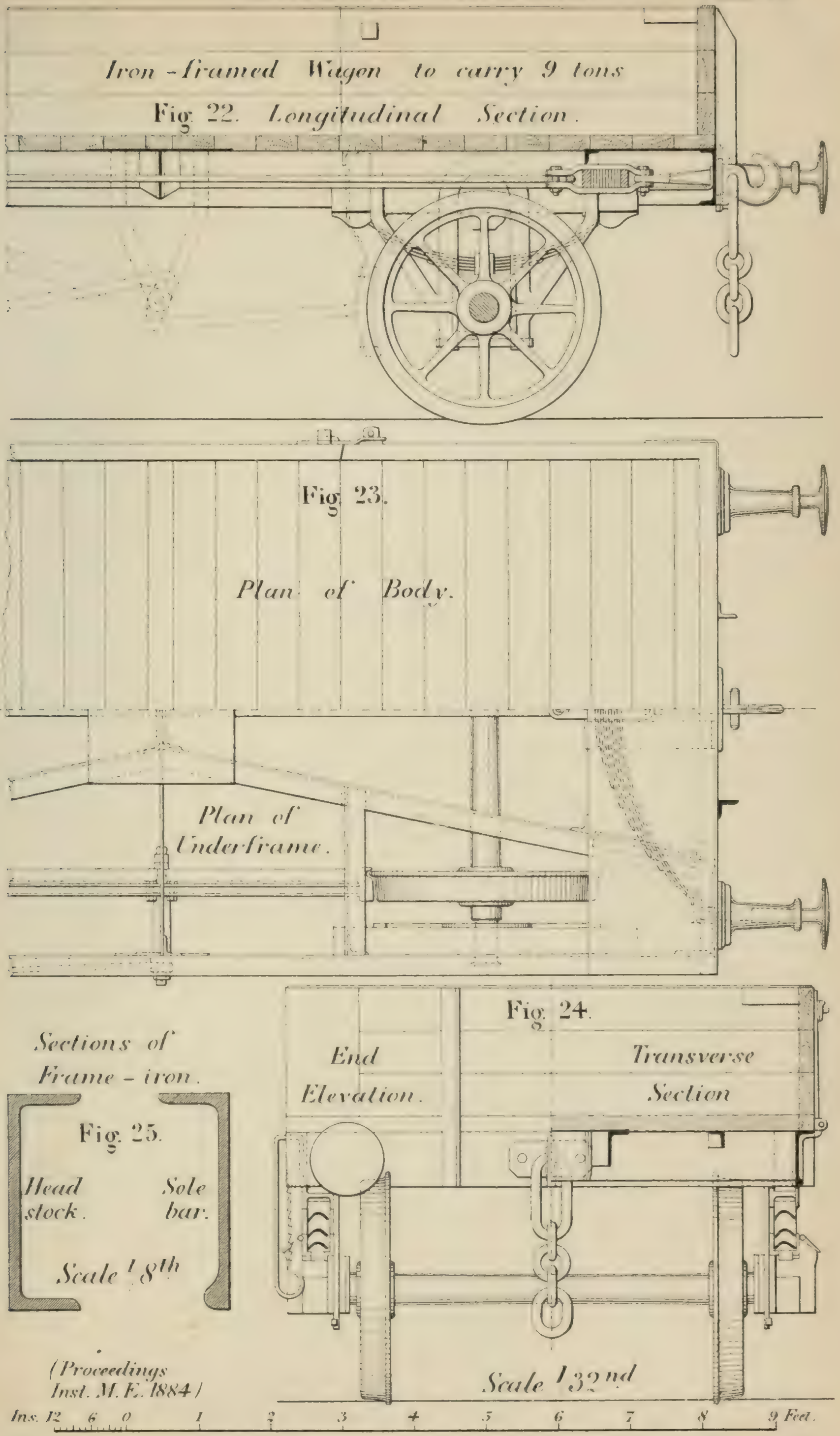
Fig. 18.



Scale 1/48th.

Ins. 12 6 0 1 2 3 4 5 6 7 8 Feet.

(Proceedings Inst. M. E. 1884.)


Iron-framed Wagon to carry 9 tons
Fig. 22. Longitudinal Section.
Fig. 23.
Plan of Body.
Plan of Underframe.
Sections of Frame-iron.
Fig. 25.
Head stock.
Sole bar.
Scale 1/8th
Fig. 24.
End Elevation.
Transverse Section
(Proceedings Inst. M. E. 1884)
Scale 1/32nd
Ins. 12 6 0 1 2 3 4 5 6 7 8 9 Feet.

MINERAL WAGONS.

Iron - framed Coal Wagon to carry 10 tons.

Fig. 26. *Side Elevation.*

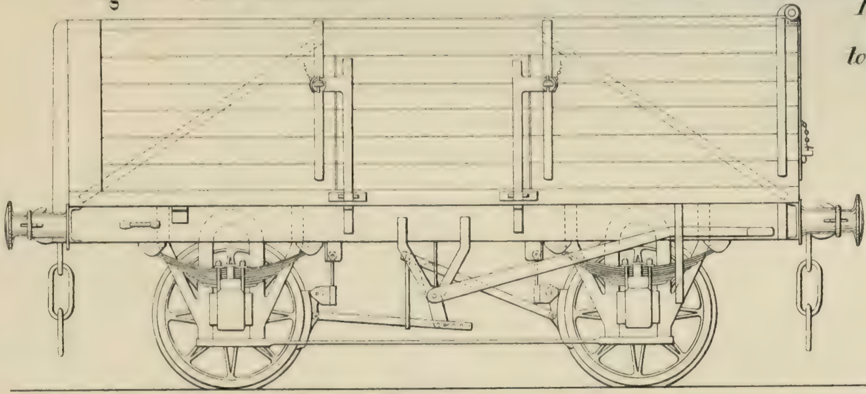


Fig. 27.

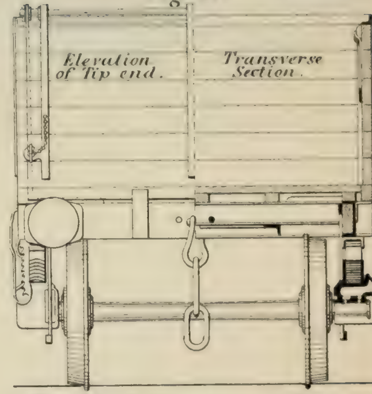


Fig. 28.

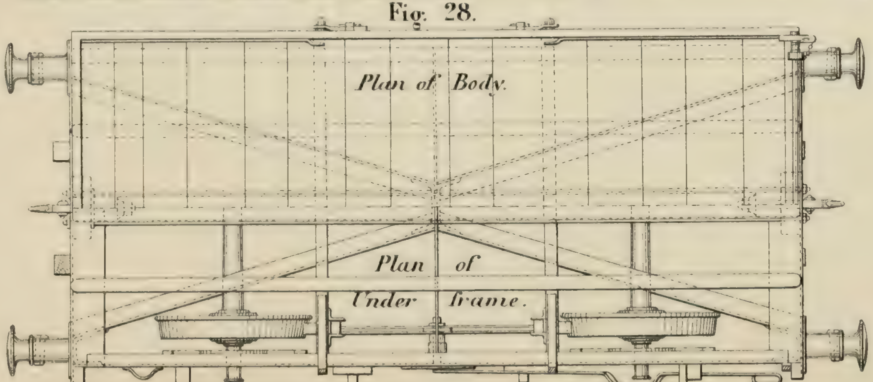


Fig. 29. *Section through Draw-bar.*

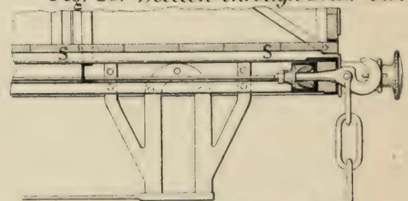
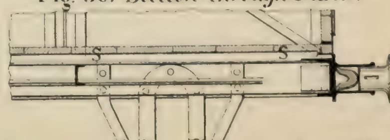


Fig. 30. *Section through Buffer.*



Scale 1/48th. Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet.

Fig. 2.

Signal worked by Single Magnet.

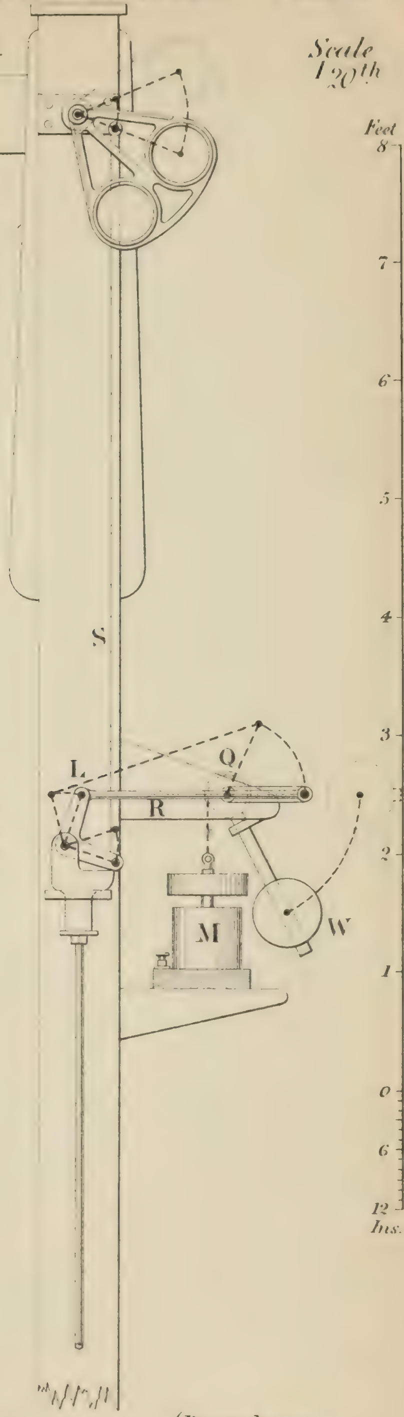
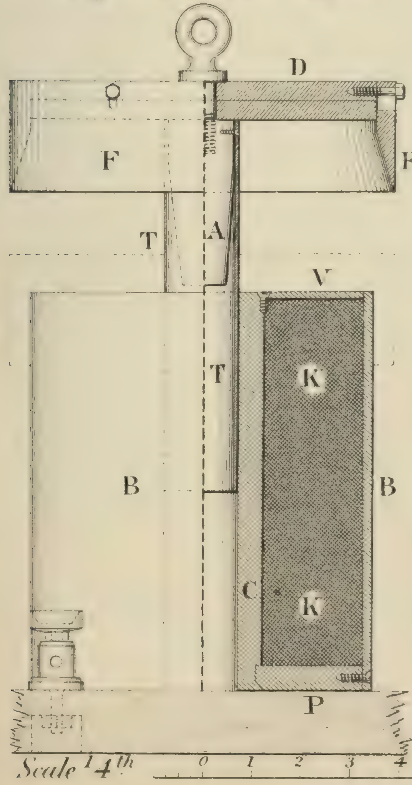


Fig. 1.

Long-Pull Electro-Magnet.

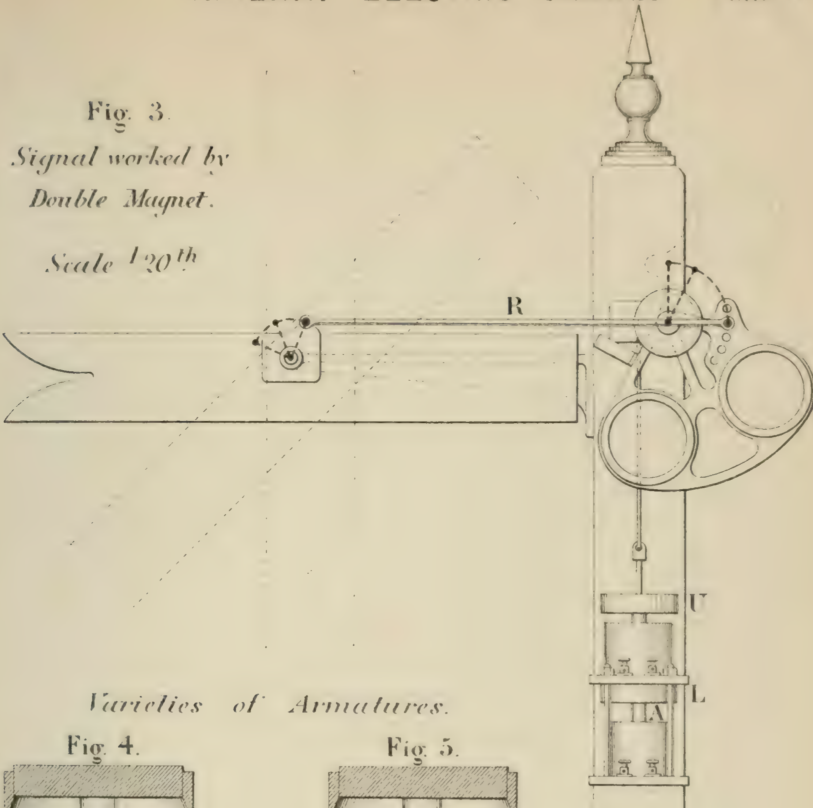


(Proceedings Inst. M.E. 1884.)

Fig. 3.

Signal worked by Double Magnet.

Scale 1/20th



Varieties of Armatures.

Fig. 4.

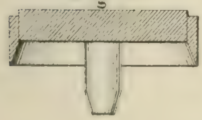


Fig. 5.

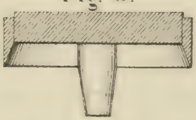


Fig. 6.

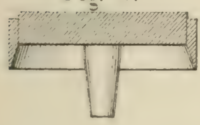


Fig. 7.

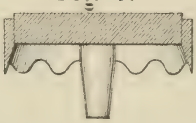


Fig. 8.

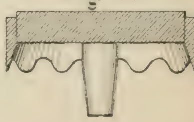


Fig. 9.

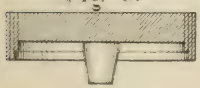


Fig. 10.

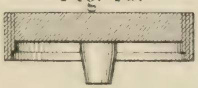


Fig. 11.

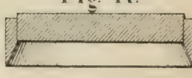


Fig. 12.

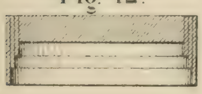


Fig. 13.

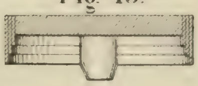
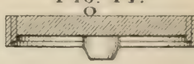


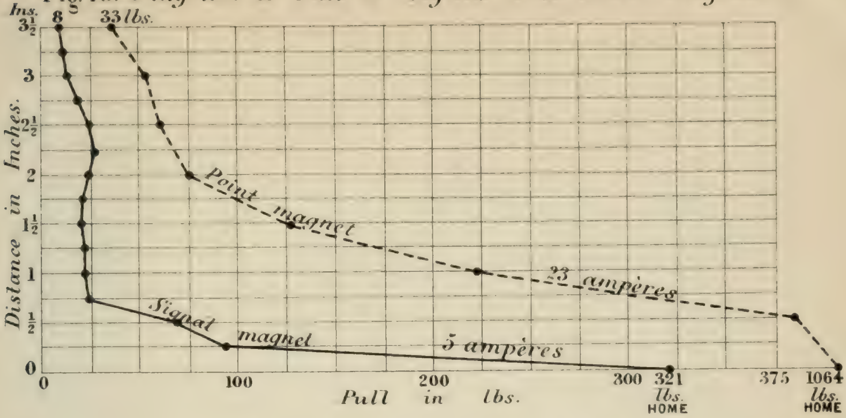
Fig. 14.



Scale 1/8th

0 5 10 Inches.

Fig. 15. *Diagram of Pull of Signal and Point Magnets.*



Switch-handles in signal-box.

Fig. 16.

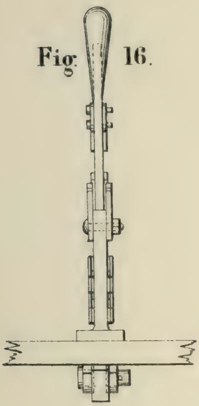


Fig. 17.

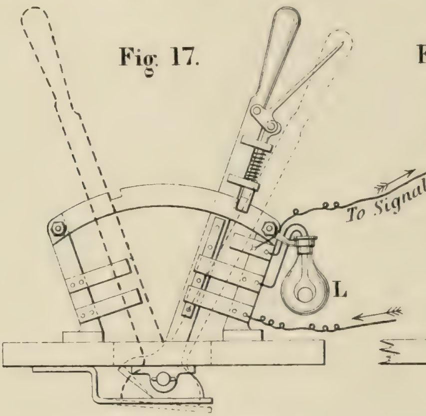


Fig. 18.

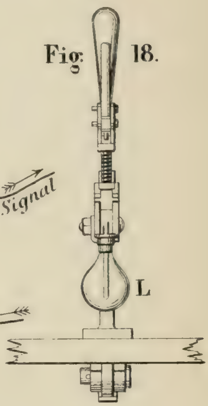
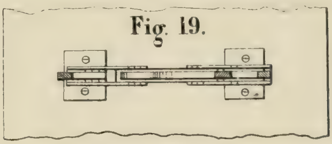
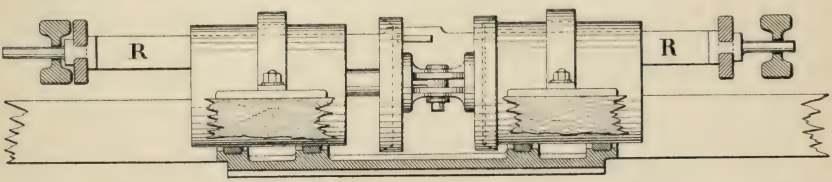


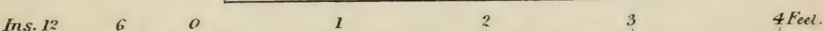
Fig. 19.



Scale 1/6th

Fig. 20. *Elevation of Electro-Magnets for working Points.*





Scale 1/16th

Points worked by Electro-Magnets.

Fig. 21.
Plan.
(Points closed.)

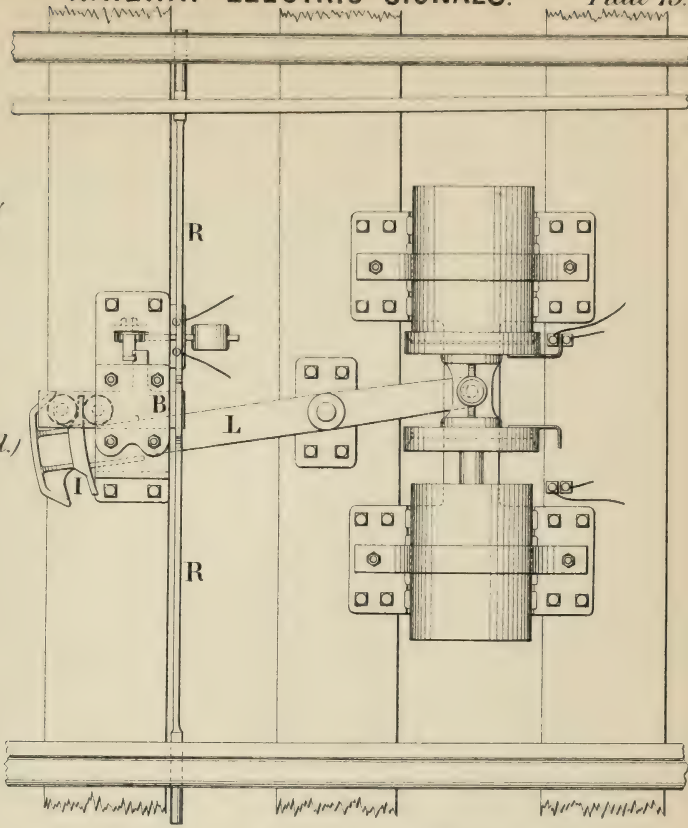


Fig. 22.
End Elevation.
(Points closed.)

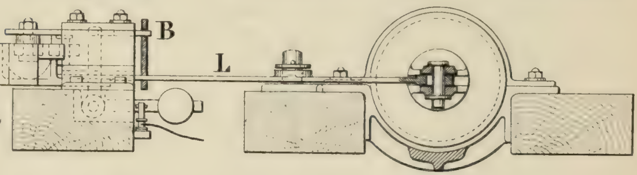


Fig. 23.
End Elevation.
(Points half open.)

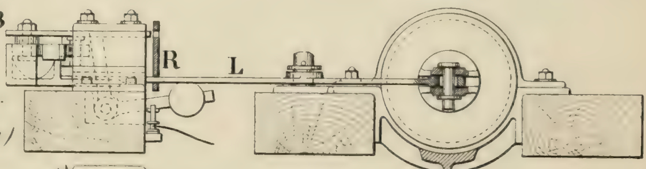
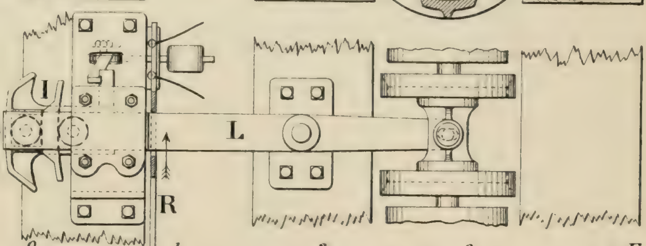


Fig. 24.
Plan.
(Points half open.)



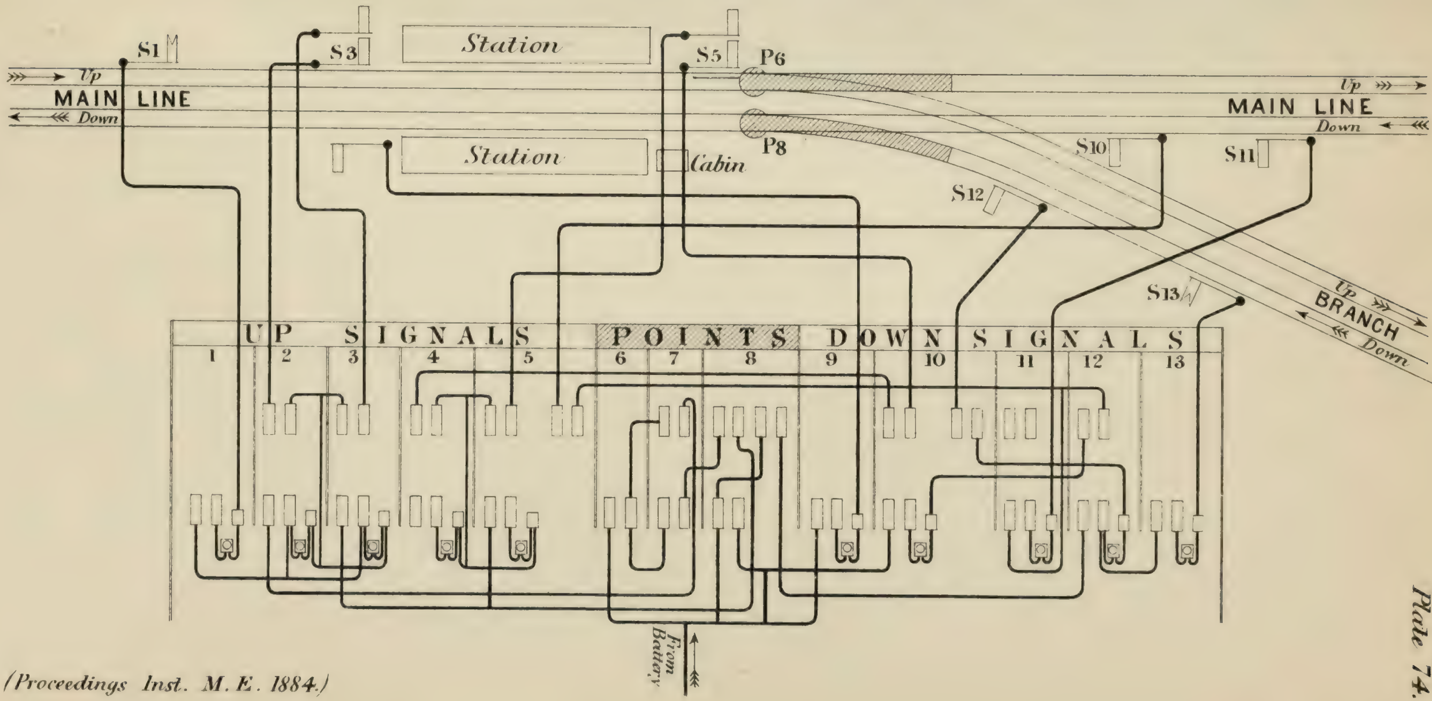
Ins. 12 6 0 1 2 3 4 Feet.

Scale 1/16th.

(Proceedings Inst. M. E. 1884.)

RAILWAY ELECTRIC SIGNALS.

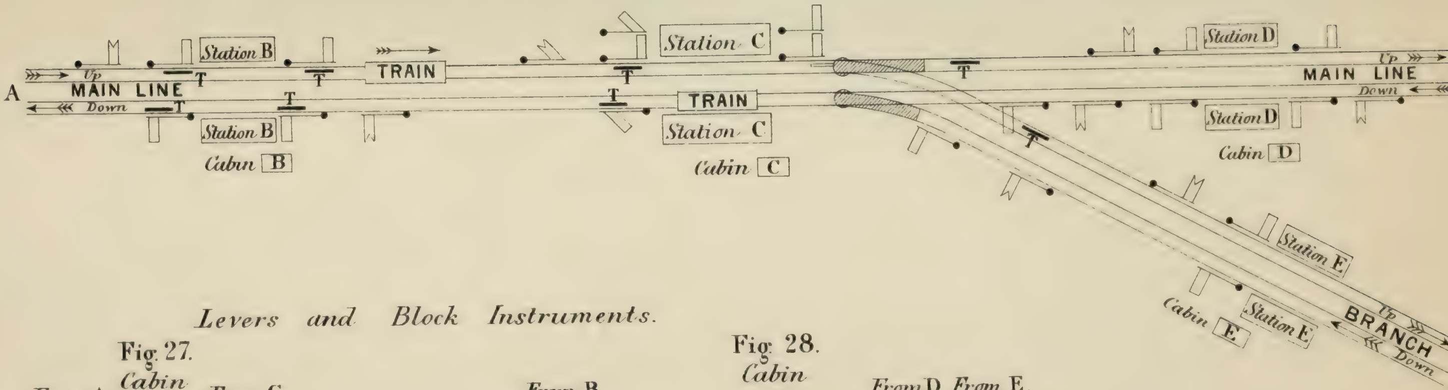
Fig. 25. *Interlocking of Points and Signals at Railway Junction.*



(Proceedings Inst. M. E. 1884.)

RAILWAY ELECTRIC SIGNALS.

Fig. 26. *Signalling from Station to Station.*



Levers and Block Instruments.

Fig. 27.

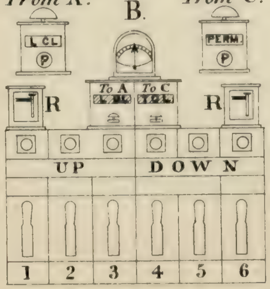
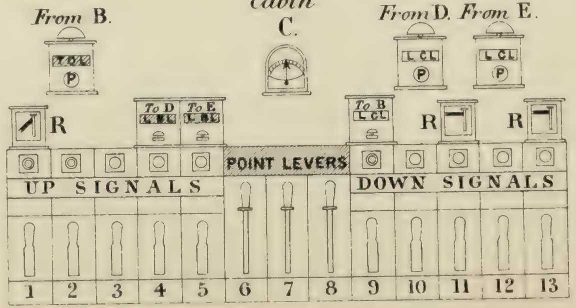


Fig. 28.



L CL = *Line clear.*
ToL = *Train on line.*
L BL = *Line blocked.*
PERM = *Permission.*

(Proceedings Inst. M. E. 1884.)

Plate 75.